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EDITED BY J. McKEEN CATTELL

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THE SCIENTIFIC MONTHLY

JUNE, 1916

THE OLDEST PLACE OF WORSHIP IN THE WORLD[1]

BY WALTER K. FISHER

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TAI Shan in central Shantung is the most noteworthy of the five sacred mountains of China and is the oldest place of uninterrupted worship in the world. In the remotest mythical period kings made regular sacrifices on the mountain top, the nearest approach to heaven known to them, and this practice continued into the eleventh century of the Christian Era. To-day a temple marks this primeval altar, and the infrequent foreigner may carelessly stand on the rocks where Yao and Shun, heroes of China's "Golden Age," made their offering to the Spirit of Heaven. In the earliest mention of the mountain, about 2,000 B.C., and probably long after it had become an object of religious regard, we find the worship described as being, not of the mountain, nor of a spirit abiding there, but of one God, a dweller in heaven. Yet from time immemorial the people have personified the mountain or imagined that it has a soul, or is inhabited by a spirit, which is alluded to as the genius of the mountain. This has been given names, which have changed in different epochs. In 1369 the Buddhist founder of the Ming Dynasty decreed that worship should be offered to Tung Yo T'ai Shan. When Taoist influence becomes predominant, Tai Shan has a birthday, and is the abode of a multitude of spirits, and has to do with the birth, death, adversity and prosperity of mortals, while the little hill of Kao Li at its foot is closely associated with the judgment of human souls after death. In the sixth, seventh, tenth and twelfth centuries the Buddhists were in control, but now their presence is scarcely noticeable. The temples have fallen into the hands of illiterate Taoist priests who seem to foster the worship of the "Lady of Tai Shan" rather than of the mountain itself. The legends of the "Jade Lady," as she was at first called, are very indefinite. She has been seen twice, first in 2600 B.C., and again about A.D. 65, as one of seven women, dressed in feathers and crowned with clouds. A more popular tale identifies her with a girl named Yu Yeh, born near Tai Shan in the year 143 B.C., who at a tender age went to live in a cave on the mountain, hoping to

[1] Photographs by the author.

TAI SHAN (GREAT MOUNTAIN) FROM NEAR THE BEGINNING OF THE PILGRIMS' WAY, which is shown on the left. The "Eighteen Flights" leading to the Heaven Gate can be seen below the notch some distance to the left of the peak. Note the gardens in the ravine.

become a fairy. After three years she is said to have attained her object. About 1008 a marble statue of the Lady was found in the Pool of the Jade Lady on the mountain-top, and this discovery seems to be responsible for her present popularity. The chapel in which this statue was placed preceded the present Lady Temple, the chief shrine at the summit. Aside from its local features, the religious fortunes of the mountain have followed those of China as a whole.

The annual pilgrimage is the most characteristic feature of the worship. The shrines are thronged with pilgrims during the first three or four months of the year. In former times they attended in hundreds of thousands, even millions, from all over the empire, but now the numbers have greatly fallen off and few come from beyond the province. The pilgrimage is the occasion of a fair in the walled town of Tai An at the south base of the mountain. Here the large Lady Temple is filled with shops of all sorts, and in the open spaces outside are refreshment venders, quacks, peep-shows, minstrels, and story-tellers. The pilgrims travel very frequently in clubs. Each member contributes a monthly subscription to the promoters until a sufficient sum has been collected. Then in the first moon (February) they set out, usually afoot, the leader carrying a flag with the name of their town and other items written upon it, while the other members often wear a red or yellow girdle. Their money is spent first on religious duties, secondly on food, fairs, gambling, and lastly in some cases on erecting a stone tablet to commemorate the names and subscriptions of the participants.

Prior to the completion of the Tienstsin-Pukow railroad it was diffi-

TAI SHAN FROM BEYOND THE HALF-WAY STATION: Heaven Gate and the steps leading to it on the left. The two conspicuous squares on the face of the cliff are inscriptions left by former pilgrims. Compare with neighboring pine tree. In the foreground the Pilgrims' Way is on the right.

cult for a foreigner to reach Tai Shan. Now the journey is a long day by train from Tientsin to a small station called Taianfu, two miles west of the walled town of Tai An, which crouches at the south base of the mountain, and from which the remarkable Pilgrims' Way sets out. Be it remembered the railroad has not brought the English language, nor the foreign hotel. Except for the trains, this part of the ancient kingdom of Lu has changed little since the days of Confucius.[2]

We quitted Taianfu in the chill of an October dawn, borne in mountain chairs by sturdy Shantung men. There were four of these chairs,[3] each carried by two men, while four extra bearers followed the caravan to relieve the others. We made a brave showing as the coolies pattered over the rough plain toward approaching day. Tai Shan looked all of its 5,000 feet. Its gaunt head and shoulders were chang-

[2] Without the aid of Mr. P. H. Henry Sze of the Tientsin-Pukow railroad, who generously acted as cicerone and supplied a comfortable private car, two American wanderers would never have beheld the cliffs of gray Tai Shan. The language alone is a sufficient barrier to a foreigner, while it requires a considerable outfit to utilize a Chinese native inn. To the Honorable Alfred Sze I am equally indebted for having suggested the pilgrimage, and for having aided in its accomplishment.

[3] These chairs consist of a square frame with a few cords stretched over it for seat, and fitted with a foot board and a low back. Two curved carrying poles are fixed to the frame with iron clamps, and are slung by long leather straps and cords over the shoulders of the bearers, who often hold the ends of the poles in their hands. In going up or down the steep mountain path, or sometimes also on level ground, the bearers walk abreast, with the occupant facing sideways between them. A third man may aid the others.

THE UPPER PART OF THE PILGRIMS' WAY, showing the Eighteen Flights and the South Gate of Heaven. The road here follows the margin of a dry torrent bed. Note the people on the road.

ing to a rosy image of the erstwhile uncompromising crags, while broad masses of shadow still clung to its uncertain boulder-strewn flanks and ravines. Greeted by dogs, we flitted past Tai An, up the broad Pilgrims' Way where so many of the lowly and great of China had preceded us. This road, ten feet in width, paved with rock and often bordered by substantial walls, clambers up ravines, over ornate bridges, meanders through venerable cypress groves,[4] jumps over ledges in

[4] Although called cypresses these trees are really large *Thuya orientalis*.

THE TAI SHAN CHAIR.

flights of steps and with a trajectory like that of a sky-rocket scales the last steep gorge and disappears through the South Gate of Heaven, nearly five miles from Tai An.

With the coming of the sun a multitude of beggars crept from near-by hamlets and demanded coppers in whining tones. Above a zone of small temples, overshadowed by ash-like huai trees, we came upon huge boulders underneath which had been constructed little cells

"THE BEARERS STOPPED FOR BREAKFAST AT A SORT OF LITTLE HALF-WAY STATION, where over acrid fires of cow-dung they brewed tea and devoured huge cakes resembling hardtacks, twenty inches in diameter."

THE SOUTH GATE OF HEAVEN (NAN T'IEN MEN). This great gate marks the entrance to the sacred precincts of the summit and is at the top of the Shih Pa Pan or Eighteen Flights. Beyond it are all the temples of the mountain-top, and a small village of thatched stone huts which line a continuation of the Way, leading to the Lady Temple. Note the chain on the left placed there to aid weary pilgrims.

in which beggars or perhaps holy folk live when the way is thronged with devotees. On the stony sides of the ravine were little garden patches, with here and there a mud-and-stone walled house. Magpies called from the cypress-clad slopes, and an occasional Chinese blue-pie stopped on a wall to inspect us. Among the numerous honorary gateways or pailows, we passed under one characteristically Chinese, for growing out of the front were two fairly large cypresses. Weeds,

THE PILGRIMS' WAY, FROM THE GATE OF HEAVEN. Looking down the Eighteen Flights, over spurs of Tai Shan. This is the steepest part of the "road," which for many hundreds of feet is a huge flight of stone steps. If one holds the picture horizontally directly below the eyes, the effect of steepness is partly gained.

bushes, and even trees adorn nearly every edifice of sanctity, as well as others of no pretensions.

The bearers stopped for breakfast at a sort of little half-way station, where over acrid fires of dry, peaty, cow-dung they brewed tea in pewter-bound, globular pots of unglazed earthenware, once white but now a meerschaum brown from long use. Fortified with this, they devoured huge cakes resembling hardtacks, twenty inches in diameter. Then

THE TEMPLE OF THE MOUNTAIN LADY. "At the end of a meandering street skirting the verge of some cliffs is the principal Lady Temple, built of stone covered with reddish plaster and roofed with yellow and gray tiles (sometimes of brass or iron)." The steps lead to the west gate (1661). The second roof to the left, that of the Gate Hall, is covered with iron tiles. The main temple is the last large building of this group, to the left. It is roofed with brass or copper tiles. Of the three temples in the upper left corner, the lowest is dedicated to Confucius. Note the thatch held down by sticks and stones.

each drew from a tube at his belt a little pipe which he deftly lit with flint and steel. The flint and tinder (soft Chinese paper rolled into a cylinder and charred at the end) were kept in a small ornamented wallet, the lower side of which had a piece of steel the whole length like the runner of a skate.

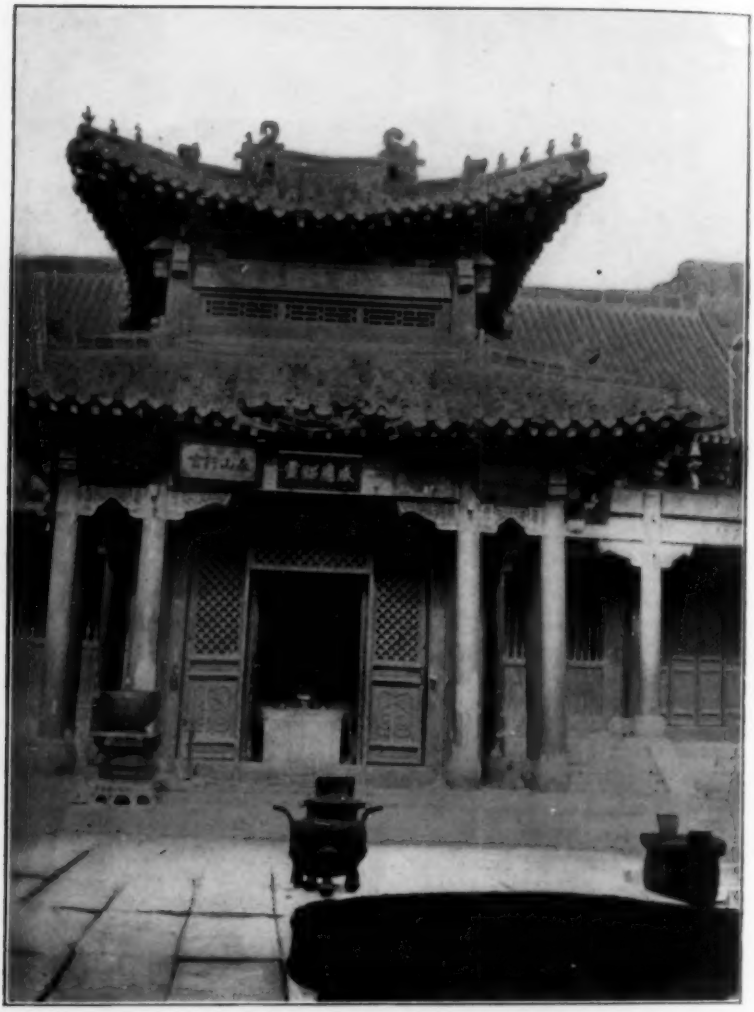
On either side of the Pilgrims' Way, deeply chiseled in the rock, are numerous inscriptions, some gigantic in size. They record the visits and thoughts of pilgrims of note. Some are poems, and of many the ideographs are archaic, perhaps antedating the present road itself.

It is pretty certain that the Way follows the course of an extremely ancient trail, yet who built it, or when, is not definitely known. It has been called the P'an Tao or P'an Lu and a book of the Han Dynasty (202 B.C.–A.D. 220) says: "The P'an Tao goes winding upward with over fifty stages (p'an) and the distance from the foot to the ancient altar is 40 li." At that time the great final ascent to the Tien Men, or Heaven Gate, evidently existed. It was called Huan Tao and pilgrims were aided in their climb by ropes. Now, cascading down a wild ravine for many hundreds of feet from the mouth of the Tien Men is the noble Shih Pa Pan (or Eighteen Flights) flanked for the last hundred feet by heavy iron chains. Those who are content to forego the exhilaration of a walk up Tai Shan are at least willing to forsake the mountain chairs on the Shih Pa Pan. Yet the coolies are said never to miss their footing.

Scattered over the bleak mountain-top at several different levels are over half a dozen groups of temples of rather conventional Chinese pattern. The site of the ancient altar on the topmost peak is occupied by a small temple to Yu Huang, a Taoist God, dating from the middle ages. The roof is protected by heavy iron tiles resembling those of clay. The ground is classic, for here in China's Golden Age were offered sacrifices to Heaven, and here many of the great scholars and statesmen of each succeeding dynasty were drawn by reverent curiosity. Confucius climbed Tai Shan and thought the empire small. Beside the steps leading to this altar is the Wu-tsu-pei, or Uninscribed Monument, a granite obelisk fifteen feet high, set up according to tradition by Ch'in Shih H'uang in the third century before Christ. On this part of the mountain are numerous inscriptions and monuments left by pilgrims. A rock called T'an Hai Shih, upon which people stand to watch the sun rise "from the sea," is not far from a cliff, whence numerous fanatics have plunged, hoping to save by their own death the life of a dying relative. A quiet, deserted-looking temple contains the sleeping image of the Mountain Lady, a figure which is dressed and undressed, put to bed and got up like a doll. Another temple partly hides a colossal monument in the form of an inscribed tablet cut in the face of a cliff. It is thirty feet high and sixteen feet wide. The characters were chiseled in 726 A.D. but are still clear after twelve centuries' exposure to the elements.

Below these temples and at the end of a meandering street skirting the verge of some cliffs is the Pi Hsia Ts'u or principal Lady Temple, built

THE TEMPLES SURROUNDING THE ANCIENT ALTAR ON THE SUMMIT OF TAI SHAN, dedicated to Yu Huang and dating from the middle ages. The altar is a knob of bare rock surrounded by a stone fence in a central courtyard. The "Uninscribed Monument" is seen beside the steps. It was erected in the third century before Christ.



THE LADY TEMPLE. A portion of the front, and the main court. In the huge incense-burner in the foreground we sacrificed a few bushels of paper temple money. Within the temple is an image of the Lady of the Mountain, along with other Taoist deities. The tiles are of copper.

of stone covered with reddish plaster and roofed with yellow and gray tiles. It is reached by flights of steps, which lead to a terrace, thence to the great Gate Hall, opening upon the main court, the north side of which is occupied by the main Hall of the temple. Within, the chief images are those of the Lady and of the deities presiding over childbirth and eyes. In this court are some old bronze incense burners, in one of which we sacrificed a quantity of temple money, purchased from a priest. This offering consisted of large disks of red and gilt paper,

somewhat resembling a Chinese kite. Properly burnt with incense it is much appreciated by the Lady of the Mountain, who has no use for the coin of the realm. In a side chapel is a very ancient stone, with traces of archaic inscriptions. It is much cracked and is propped together by stones. But in these temples, as elsewhere in China, the visitor without the language of the country is practically lost. Information from the priests is vague and unrelated. The traveler must piece together the disconnected bits by a vast amount of surmise, and restrain his curiosity until he can "read up," perhaps a year later when he reaches home.

This Pi Hsia Tz'u is the most wealthy of the shrines on Tai Shan and owes its origin to the discovery of the Lady's image in the Pool of the Jade Lady. The first temple was built in 1008. It was rebuilt on an elaborate scale in 1585, but was destroyed by fire in 1740 and reconstructed with considerable change in 1770.

Bordering the road which winds around the south face of the mountain from the Heaven Gate to the Lady Temple are picturesque stone huts, the roof thatch bound tight against the winter winds by strips of cane or bamboo. On the opposite side of the way, next to the wall above the bluffs, are massive stone tables between stone trenches, the tables marked into squares for some game like chess. Within, the cottages are smoked to a shiny blackness by the dung fires and streamers of soot are pendant from the dusky region of the thatch. They are occupied mostly by old people, two of whom hospitably gave me hot tea and took a childish delight in my interest in their simple belongings. The fire is made in a raised stone hearth, in the top of which are several apertures for the accommodation of iron saucepans and pewter kettles. The water flasks, lamps, dippers, and tea-pots are all of excellent design. The tea-pots are of earthenware, with pewter handle and spout, and stained a rich brown by long use. Silver would not tempt the old man shown holding temple money to part with his, for he told Mr. Sze it had been in the family for five generations and was very precious to him. The interiors are all very simple. Besides the raised hearth, there is a large earthenware water jar near the door, sometimes a rude table, and at one or both ends of the room a broad raised platform of coarse matting or basket-work which serves as a bed and a settee. When the door is closed there is little light. These dwellers within Heaven's Gate lead a life primitive in the extreme, and the rigors of winter must be severe on the old folks, unless perchance they all migrate to the plains.

Finally, what is Taoism? It is commonly supposed to be the philosophy of Lao-tsze who, between 500 and 600 B.C., wrote the Tao Teh King. In practice it is no such thing. Lao-tsze taught the Tao, or the "Way," concerning himself, as did Confucius, his contemporary, with ethical principles, the conduct of the individual and of society, and not at all with religion. The Tao was "the simplicity of spontaneity,

ONE OF THE NUMEROUS INSCRIBED ROCKS ON THE TOP OF TAI SHAN.

action without motive, free from all selfish purpose resting in nothing but its own accomplishment." This is found in the phenomena of the material world.

> All things spring up without a word spoken, and grow without a claim for their production. They go through their processes without any display of pride in them; and the results are realized without any assumption of ownership. It is to the absence of such assumption that the results and their processes do not disappear (Chap. II.).

He applied this principle to the government of society and the individual. His teaching reaches its highest levels in the following:

DWELLINGS WITHIN THE GATE OF HEAVEN. "Bordering the road which winds around the south face of the mountain from the Heaven Gate to the Lady Temple are picturesque stone huts, the roof thatch bound tight against the winter winds by strips of cane or bamboo." This village is called the T'ien Chieh, and the picture is from the foot of the steps leading to the Lady Temple.

It is the way of Tao not to act from any personal motive, to conduct affairs without feeling the trouble of them, to taste without being aware of the flavor, to account the great as the small and the small as the great, to recompense injury with kindness.

There is scarcely a word of Lao-tsze which savors of superstition or religion. Taoism to-day is a system of abject superstition. It did not take shape for more than 500 years after the death of Lao-tsze.

INTERIOR OF A TAI SHAN HUT. To the left is the stone stove with cooking utensils and, beyond, a table. On the right is a large water jar in front of a table set "for ten." The old men are sitting on one of the bed platforms; the photograph was taken from the other. There is a broom leaning against the stove.

OLD MAN WITH TEMPLE MONEY. This old man sells temple money to be burned at the altar of the Lady of the Mountain. It is made of red and gilt paper. Note the quilted coat and trousers and the fur cap with ear flaps.

In the first century A.D. a magician Chang Tao-ling is the chief professor and controller of this Taoism, preparing in retirement the pill which renewed his youth, supreme over all spirits, and destroying millions of demons by a stroke of his pencil.

It was not until about A.D. 70 that the system borrowed temples, monasteries, liturgies and forms of public worship from the Buddhists and set up business as a religion. After assuming the form of a religion it continued to degenerate until now it is "in reality a conglomeration of base and dangerous superstitions" fused with a system of the wildest

polytheism. Alchemy, geomancy, spiritualism and black art generally flourish under its shadow. Each of its three Holy Ones (of whom Lao-tsze is one) has the title of Tien Tsun, "The Heavenly or Honored," taken from Buddhism, and also of Shang Ti, or God, taken from the ancient religion of the country. To the myriad of other demigods and spirits are added many of merely local import, as the Lady of Tai Shan.

As one looks from Heaven's Gate, down the long Pilgrims' Way and into the golden haze that lingers over the Cradle of China, he seems to conjure up that solemn procession of people and kings of old Cathay, stretching in an unending line to the dim legendary realm of a heroic age. Dynasties have risen and died, yet the innumerable multitude with each recurring spring has been drawn hither as by a titanic lodestone. Each has had his own quest, and, doubtless, in spite of the trumpery of childish superstition, many now find solace on the mountain top. Yet while blindly following the Pilgrims' Road has not the great host wandered far from the "Way" which was blazed for them in the braver, saner days of old?

THE EVOLUTION OF THE EARTH[1]

II. Earth-Growth

By Professor THOMAS CHROWDER CHAMBERLIN
THE UNIVERSITY OF CHICAGO

IN the view that was dominant during the last century—perhaps dominant still—the earth, when it had emerged from its natal conditions and had become a mature planet, was pictured as a molten globe surrounded by an atmosphere embracing all such earth-substance as would be volatile at the temperature of white-hot lava. The earth must then have been a perfect sphere, except as rotation imposed a symmetrical deformation upon it, and even the details of its surface configuration scarcely departed from the contours of a perfect spheroid. Its internal structure must have been symmetrical, the denser material at the center, the less dense in concentric layers about this, the least dense at the surface. Each layer should have been essentially homogeneous in itself. The stresses within the earth, at first, must have been purely hydrostatic, increasing necessarily from the surface to the center.

The evolution of the earth under this concept was actuated by changes of energy within the hot young planet itself, chiefly loss of energy by radiation. At an early stage of this loss, a crust formed over the uniform surface of the symmetrical spheroid, dividing the fluids below from the fluids above. On this crust, the vapors descended, and a universal ocean followed; and then—if we pursue the picture so impressively painted by the old masters in geology—there was a prolonged battle between fire and water, the ocean penetrating to the hot material beneath it and arousing explosive action of a spectacular sort. Lateral thrusts arose from the shrinkage of the cooling globe, followed by bowings, foldings and fractures. Here and there, the crust emerged from the universal ocean and the great contest between the sea and the land was initiated. Thus the postulated evolution was made to arise in simplicity and to go forward in a symmetrical, logical way. It was pictured with great impressiveness—not infrequently with a touch of eloquence, often with a touch of poetry—by the masters of geology in the middle of the last century.

We owe these old masters a tribute of gratitude for the clear views

[1] Third series of lectures on the William Ellery Hale foundation, National Academy of Sciences, delivered at the meeting of the Academy at Washington, on April 19–21, 1915.

they set forth, and for the logical fidelity with which they followed the premises they adopted, a fidelity largely lost in these later years, by the adherents of the same cosmogonic tenets. This lapse is not without reason, for the later students of the earth have been compelled to accommodate their views to new disclosures of stubborn realities that do not fall into obvious accord with the cosmogonic antecedents so sharply postulated in the earlier years. It is perhaps not far from the truth to say that, in recent years, few geologists have tried to follow rigorously the cosmogonic tenets handed down to them. Usually they have contented themselves with shaping their views to fit the more specific aspects of the phenomena they have had immediately under consideration. A multitude of divergencies from the simple tenets of our forefathers have thus arisen and have come to penetrate modern geologic literature in a most intricate way. The stubbornness of the realities revealed by progressive inquiry has amply justified a swerving from inherited tenets. It has equally invited a loosening of the hold of doctrines that depend on these tenets. In recent years the insubordination of new determinations to old interpretations has risen to declared refractoriness. The old problem of the origin of the continental embossments and the abysmal basins, the problem that lies at the very threshold of earth science—always a troublesome problem, because of the great range of the inequalities—has lately assumed a new form and become a burning question of the hour. Under the stress of time-limits, let us take this as a type of a large class of new issues. I refer to the fundamental question that lies beneath the growing doctrine of isostasy, the origin of the differentiation of specific gravities deep in the crust of the earth necessary to actuate isostatic movement, the very basis of isostasy. In this lies a grave challenge of the molten concept of the primitive earth. Very cogent reasons have been adduced from geodetic data, particularly by Hayford and Bowen, for the belief that the protrusions of the continents are in isostatic balance with the depressed segments beneath the oceans. It is hence inferred that the material beneath the continents is as much lighter than that beneath the oceans, as the former are protrusive and the latter depressive; in other words, the difference in the specific gravity of the rock columns beneath the continents and beneath the oceans, respectively, must extend far enough down to compensate for their differences of height. A great mass of refined observations support the isostatic view, at least in its major features.

But from the earliest days of geologic record, the atmosphere and the hydrosphere have been persistently cutting away material from the continents and depositing it in the basins, while the continents have been pushed up, at repeated intervals, and the denudation renewed, else the sea would long since have crept over the whole land. Many thousands of feet have been cut away from the oldest known lands. Now

this implies that the low specific gravity beneath the continents has been deep enough and great enough to actuate isostatic movement, again and again, as the unloading of the land and the loading of the great water-basins has required. Differences of specific gravity adequate to this must have had a competent source; the differentiation must have been deep enough and great enough to have retained its efficiency through all the ages in spite of the persistent efforts of denudation and transportation to effect an equilibrium, not only, but it must have been great enough to leave the present undetermined resources available for future isostatic movements.

Now in a molten earth there should have been, at the start, a perfect isostatic balance, in the fullest sense of the term. An adequate cause for any non-isostatic differentiation in such a liquid mass seems wholly unassignable; certainly it has not been assigned; on the contrary, there are the most obvious reasons why the state of gravitative balance should have been initially perfect under the molten theory and should be preserved, for the dominant tendency of surficial action is perpetually toward equilibrium. The agencies within, like the agencies without, should have worked hand in hand to maintain the isostatic stability inherited from the original state. The present state does not, therefore, seem to flow logically from the assigned initial state.

But the case does not rest alone on logic, however cogent. If, in some unexplained way, there arose a deep differentiation of specific gravity of one type beneath the continents and of the opposite type beneath the oceans, and if the continents were thus forced to rise as their surfaces were cut away, the original embossments would, by this late day, have been cut down many thousands of feet, and we should now have free access to this much of the original molten interior of the earth. Our geologic forefathers, with their logical fidelity, so interpreted the deeper terranes so exposed in the heart of the old embossments, and some of us were indoctrinated with this concept in our youth. But as soon as petrologic science had come into possession of its modern efficient tools, it was discovered, almost simultaneously in the several critical regions then under competent investigation, *that the oldest known rocks are surface rocks and that the supposed original igneous rocks of the sub-crust are merely local intrusions.*

Taken together, these determinations constitute a formidable obstacle to the further acceptance of the inherited view. There is an absence of such observational testimony in support of the hypothesis of a once molten interior as we have a right to expect, such indeed as our geologic forbears did expect, not only, but supposed they had found. There is now added to this deficiency the adverse implications of such a deep differentiation of specific gravity as to force deformative readjustments, even at this late day, in spite of all previous partial adjustments.

This seems quite incompatible with a primitive molten state of the earth. To some of us its adverse import is wholly decisive. If there is a line of escape, consistent with logical fidelity to observed facts and physical principles, I must leave it to others to find it.

But we are less concerned with doctrines that fail than with doctrines that seem to hold out working promise of a true interpretation. The renewed protrusion of the continents and the continued receptivity of the oceanic basins, constitute the working prerequisites of geology, the very *sine qua non* of our science. The verity of their initiation and their maintenance throughout all recorded geologic history must be justified by any system of doctrine that has any claims to serious consideration. We feel, therefore, the call to dwell, in proportion to their importance, upon these fundamentals, in respect to which faith has been so much disturbed by recent disclosures.

The cosmogonic postulates set forth in the last lecture gave a specific working basis for an alternative picture of the early states and of the basal constitution of the earth. Briefly, these were a nebulous knot, as a center of growth, and much scattered nebulous matter as food for growth. The central portion of the knot was probably in a dominantly inter-collisional state, while the outer portion was almost inevitably in a dominantly orbital state, the latter circling about the former and limited outwardly by the sphere of control of the knot. The intercollisional portion should have rapidly collapsed into a dense spheroid so far as composed of rock-substance. The portion that revolved about this, after the manner of minute satellites, *i. e.*, satellitesimals, was collected only as the occasional collision of one satellitesimal with another drove them from their orbits into the earth nucleus or into the moon nucleus, or else they were driven in by infalling bodies from without, *i. e.*, planetesimals. The aggregation of the knot was not then a simple matter of gaseous collapse by cooling. What portion of the knot belonged to the intercollisional and to the orbital categories, respectively, is at present indeterminate, but progressive study tends to increase the probabilities that favor the orbital state and to diminish those that favor the intercollisional state. The nucleus of the knot that condensed in gaseous fashion to form the primitive core of the earth may have been no more than a minor fraction of the adult earth.

The scattered matter of the nebula, outside the knot, could apparently have been in no other than a state of movement about the sun. The scattered integers, whether moleclues or small aggregates, must apparently have pursued orbital paths of planetary type about the sun, that is, they must have been minute planets, or planetesimals. These were liable to fall into the earth knot in the course of their revolutions about the sun. The process must have been slow, as was also the ingathering of the satellitesimals of the knot, but each aided the other.

Internal Reorganization

An important deduction from such a genesis is the extreme heterogeneity it must have given the substance of the earth and the internal reorganization that such heterogeneity must have induced. There should have been, to be sure, some selective action, because the more inelastic material would concentrate faster than the more elastic matter, and the magnetic material would doubtless be gathered into the core, if it were magnetic, as is probable, faster than the non-magnetic material, but nevertheless much heterogeneity must have prevailed.

The atmosphere should also have served a distributive, as well as a slightly selective, function. As the planetesimals plunged into the outer atmosphere of the juvenile earth, they must have been largely dissipated into dust, if we may judge from the effect suffered by meteorites. These are largely consumed in the very thin upper air; only a very small fraction reach the earth's surface, and these are perhaps more massive than were the planetesimals. The planetesimal dust so generated no doubt floated long before it found final resting place on the earth's surface. Whatever heat was generated in the plunge into the atmosphere must have been largely radiated away from the upper regions, and the temperature of the accretional portion of the early earth could scarcely have been high.

The distribution of the accessions to the earth was thus incidentally conditioned by the atmospheric circulation. Descending currents naturally took precedence in bringing the dust down, but their dryness and turbulence near the earth's surface tended to hold the lighter material longer in suspension than the heavier; the action was hence slightly selective. Precipitation, largely associated with the rising currents, brought down all classes of dust within its reach. The first lodgment was further modified by the waters of the juvenile earth with some further selective action. On the other hand, the internal agencies that shaped the earth-body, potentially shaped also the work of the waters, for these followed the slopes of the land and gathered in the basins of the growing surface. Both the irregularities of the surface and the water, in turn, modified the circulation of the atmosphere that swept over them. And so the shaping of the earth-body by planetesimal growth was the composite product of the three great geologic factors, the atmosphere, the hydrosphere and the lithosphere, and should have been appreciably differentiated in specific gravity.

The Internal Structure of the Earth

The material of the accessions should have taken on a more or less stratiform arrangement under the action of the atmosphere and hydrosphere. Such molten matter as was poured forth from within likewise

should have assumed a rude stratiform arrangement. The combined effect of these processes was to give the earth a concentric structure, built up of very heterogeneous matter.

At the same time there were processes that tended to develop a radial structure traversing these stratiform layers much as the medullary plates of a tree trunk traverse its concentric layers of growth. Such lavas as rose from the depths doubtless either insinuated their way through seams, crevices, schist planes, and other lines of weakness, or fluxed pathways for themselves along ducts of their own making. In addition to these, the compressions that arose from growth, from transfers of molten matter from the depths to the surface, from changes of temperature, from molecular rearrangements under pressure, to secure greater density, all contributed to readjustments, recombinations and recrystallizations accommodated to the stress-differences whose least axis usually pointed in the direction of the surface. Lateral compression is a familiar phenomenon, vertical schistosity is its normal result. Diastrophic agencies came into action at a very early stage, and hence at a low horizon within the earth and their effects upon the structure of the earth were extended upward to the successive layers that were added at the surface. The earth is thus supposed to have acquired a vertical schistosity which had its initiation at great depths.

Partial Liquefaction and the Preservation of Solidity

The system of internal liquefaction and extrusion, assigned under the accretional hypothesis, departs rather radically from inherited views based on a supposed molten globe. It therefore invites critical consideration. Neglecting the very heart of the earth that is supposed to have grown from the gaseous nucleus of the knot of the nebula—the conditions of which are least certain and whose proper treatment is inhibited by time—let it be noted that the matter gathered to the earth-nucleus as aggregates, or as accretional dust, was highly heterogeneous. Assuming that it was cold when deposited, heat arose from compression as layer was added to layer. Such radioactive matter as the accessions contained also generated heat at multitudes of minute points. The increasing pressure, so far as uniform on all axes, antagonized liquefaction. With such a slowly rising temperature, so distributed and so antagonized, it may be assumed safely that liquefaction would start, so far as it started at all, with those points where particles mutually most soluble or most fusible were in contact with one another, or where most heat was generated by radioactive action, or where the two cooperated. If the mobile matter so generated slowly were removed about as fast as it gained workable volume, the main surrounding mass would remain solid. We have just named a list of stresses that may well be held competent to force at least all the lighter liquids toward the surface. We shall presently discuss these further.

It is now known from concurrent evidence—the most conclusive of which springs from the recent work of Michelson, Gale and Moulton on the body tides—that the earth is highly rigid and elastic. Aside from cosmogonic considerations, the grounds of which we have already challenged, we know of no reasons for assigning the earth any other than the rigid state, at any time during the geologic ages. The planetesimal hypothesis assumes that the elastic rigid condition prevailed, at least in the outer half of the earth, throughout the history of its growth. It holds that the accessions were added in the solid state, and that such liquefaction as later arose in this solid matter must always have been merely partial and selective, and that the liquefied material was forced, by prevailing stresses, to the surface as fast as it reached working volume. This is a radical departure from the inherited concept of a molten interior. The stresses that are believed to affect the interior of the earth are serious obstacles to the supposed existence of great reservoirs of liquid matter, lying quiescent for long ages, and undergoing magmatic differentiation under assumed static conditions. The great distortions that have certainly affected the earth to the greatest accessible depths and that are most intense in the deeper rocks, seem to be specific evidence at variance with the assumption of such protracted quiescent conditions. The newer view postulates effective stress conditions permeating the globe at all times during its adolescent, as well as adult, history, and that these effective stresses tended to force to the surface all mobile materials, except possibly some whose specific gravities were sufficiently high to resist the ascensive pressure.

The new view makes its first and most fundamental appeal to the differential stresses imposed by changes of rotation. The primary stresses of rotation give evidence of having been the greatest that have been imposed upon the body of the earth, except those of gravitation, which are hydrostatic. According to Sir George Darwin, the rotational stress-differences are eight times as great at the center as at the surface. The potential stress-difference that would become actual at the center of the earth by the arrest of the existing rotation amounts to 33 tons per square inch. The tidal stress-differences have a similar distribution, but they are relatively feeble, though persistent and pulsatory. The more general class of stresses that arise from loading and unloading through erosion and transportation perhaps have a somewhat similar distribution. The static stresses due directly to gravity, range from one atmosphere at the surface to about three million at the center. From these cooperating stresses, a persistent urgency to escape to the surface is believed to have been brought perpetually to bear on the mobile and, in the main, lighter liquid material as fast as it was generated. The less soluble, more refractory, and, in general, denser material remained behind, but probably approached mobile conditions sufficiently to permit rather

free molecular rearrangements, especially such as would give higher density. Under the general principles of endothermic action, heat-absorbing combinations may be assumed to have taken place with corresponding limitations of liquefaction. Crystalline rearrangement in the interest of density, and at the same time consistent with high elastic rigidity, is thought to have been favored and to have taken such forms and mutual relations as to give schistosity favorable to deformative movements.

Such liquefaction as took place would consume heat, in addition to that of the endothermic recrystallization, while the escape of the liquid material to the surface carried out this latent heat, as well as a due portion of sensible heat. Incidentally, the escaping lavas carried out also radioactive substances and gradually reduced the heating process. The compressibility also declined with the progress of compression, and this source of heat also declined. With compression and with the increase of static pressure, the rigidity should have increased. So the complex process inherently tended to an end of its own making.

The process of vulcanism is thus made a means of removing to the surface the excess of internal temperature, as it arises, together with the source of that temperature, performing in this way a service closely analogous to the process of perspiration in the animal body. This view is eminently consistent with the tidal and the other astronomic indications of the elastic rigidity of the earth that have recently become so declared, and also with seismic data whose evidence is less complete, though strongly tending in the same direction. It is also in harmony with the conclusion, reached by special students of the subject, that radioactive substances are chiefly concentrated at the surface. Still further, it is in harmony with the acidic composition and the low specific gravity of the outer part of the earth. The view seems also to be in fair consonance with what is known of the eutectic nature of rocks, the selective production of magmas, and the progressive differentiation of magmas, both in their ascensive and in their descensive careers.

Such effusive matter as reached the surface in the earlier stages was buried later by the infalling planetesimals and planetesimal dust, and so it was again subjected to selective processes, with further differentiation, and this might be repeated again and again, so that, in the end, there was a progressive concentration of the more refractory and the denser material toward the central parts, and of the lighter and more solvent, toward the outer parts. This selective action was of course superposed upon the selective ingathering of planetesimals, dependent upon magnetic and inelastic properties, and upon the selective action of the atmosphere and the hydrosphere. Thus, under this concept, the earth came to its maturity slowly under selective agencies that tended at all stages to differentiate its material.

So also, under this concept, deformative agencies came into action early and persisted through all stages of growth, though at all times more or less periodic in their specific manner of action. These deformative agencies now claim our attention.

Origin of the Great Physiographic Features

The most notable of past attempts to account for the continental embossments and the oceanic basins, in accordance with the theory of a molten earth, was undoubtedly that of Lothian Green, who appealed for his first premise to the fact that a spherical surface embraces the maximum of matter within the minimum of surface, and that this should have obtained in the primitive state of the earth. For his second premise, he urged that the globe, when forced to shrink from cooling, would tend in the direction of that symmetrical form which had the minimum of content with the maximum of surface, the tetrahedron. The cogency of this logic I must leave to your own judgment. On this concept, arose the doctrine of the tetrahedral earth. Assuming that the duodecahedral form of the tetrahedral type was early attained, Lothian Green located the continental protuberances at certain of the angles and the oceanic basins at alternate angles. The logic was frankly based on the doctrine of a molten earth and does not seem to be transferable to an accretional earth.

Under the planetesimal view, it seems scarcely less than necessary to assume that the great differentiations of the earth's surface arose from specific deformative stresses that came into action early in the process of growth and were more or less recurrent throughout the whole adolescent history of the earth. The controlling influence that gave shape to the juvenile earth seems to have arisen from changes of rotation. Rotation is far and away the greatest of all the deformative agencies to which the earth has been subjected. Its residual effect—not its total effect—is now seen in a radial difference of thirteen miles between the polar and the equatorial radii, but this is only the net result of a long series of earlier effects of opposite phases. The rotational stresses permeate the entire mass of the earth and, as already remarked, are greater at the center than at the surface. Such pervasive and penetrating stresses are preeminently suited to produce broad, deep, and pervasive deformative effects. The breadth and symmetry of the direct rotational effects are seen in the great graduated equatorial bulge and in the broad graduated polar depressions. This symmetrical distortion of the sphere satisfies the *primary* demands of rotation *but not the incidental demands of changes of rotation.*

The bulging and the depression of these broad tracts involved tension and compression in the segments so affected, and lines of accommodation to these stresses were requisite. It is assumed that these

lines of accommodation would define as few broad divisions of appropriate form and magnitude as would serve to satisfy their main requirements, leaving minor requirements to be satisfied by minor accommodations. It is assumed further that these major divisions would be so related to one another as to act reciprocally, one set rising in the equatorial regions, the other set sinking in the polar regions, and the reverse, according as the rotation was accelerated or was retarded. Since the earth is held to have been a rigid body, it is held—and this will bear emphasis—that the units of action would be as few as could fairly satisfy the main demands of the case, and that these parts would be as simple and symmetrical in their forms and in their working relations to one another as practicable.

The probabilities of successive oscillations between acceleration and retardation of rotation are dependent on the specific history of the formation of the globe. Under the planetesimal hypothesis, a part of the earth's rotation was inherited from the knot that formed its center of growth, but an important portion also arose from the momentum of infalling planetesimals. In the nature of the case, some of the infalls tended to accelerate rotation, while others tended to retard it, and so changes in the ratios of these two classes, arising from irregularities in the distribution of the planetesimals, tended to change the rate of rotation. Time does not permit me to give reasons for the conclusion that there was an *equilibrium rate of rotation* about which oscillation should have been an inherent tendency.[2]

Now with every increase of acceleration there was depression and crowding at the poles, while there was bulging and tension at the equator, and between these rising and falling areas there was a neutral or fulcrum zone which neither rose nor fell, but under which a shift of matter took place from the depressed to the lifted side. With every retardation of rotation, there was the opposite effect. No portion of the earth was free from these influences. Just how the earth accommodated itself to these profound stresses is our problem. So far at least as the tensional alternative is concerned, there are many phenomena in nature that teach us how the easement is accomplished, and where the yield tracts lie. There are some which show us less simply and less unequivocally how relief from compression is effected. The most instructive example is found in the cooling of lava into basaltic columns. From a study of these, it is seen that the required accommodation is effected by three parting planes diverging from the points of greatest tensional stress, at angles of about 120°. There is, of course, much variation from this precise angle when the material is even moderately heterogeneous, for the action is but a mechanical accommodation of the

[2] These are given in "The Origin of the Earth," now in the hands of The University of Chicago Press.

stresses, and has none of the precision observed in the formation of crystals.

On the basis of this principle of action, it is assumed that a threefold partition would obtain at each of the poles when under tensional stress, and that the yield tracts would extend to the fulcrum zones. The position of the two fulcrum zones would shift with the degree of oblateness, but they may be conveniently spoken of as lying not far from 30° latitude north and south. The segment so defined surficially would form only one half of the reciprocating unit. This, as seen on the surface, would have the form of a spherical triangle. The other half-unit that must cooperate with this one in reciprocal action, could be formed in the simplest and easiest way by similar yield lines crossing the equatorial belt and converging to a point in the fulcrum zone of the opposite hemisphere. The reciprocating pairs would thus consist of similar triangles—at the surface—back to back, the one wholly in the rising area, the other wholly in the sinking area. Three such reciprocating pairs would then surround each pole. If one set took precedence, as would be natural, the other would be forced to alternate with it. The two sets would thus interlock across the equatorial belt. Each working pair of triangles would form a quadrilateral at the surface, and would extend to the center, where the six apexes would come together. The earth would thus be divided into six pyramidal sectors, symmetrically related to the axis of rotation, symmetrically related also to the stresses to which they must yield, and embodying a very simple mode of meeting the requisite changes of form. This concept of a hexafid earth has some resemblance in form to the factors of the tetrahedral earth of Green, but it starts from entirely different premises and is based on radically different considerations. The hexafid division is in no sense a crystalline process, but merely a mechanical adaptation to variations of stress imposed by the pervasive effects of changes of rotation.

But no very close approach to perfect hexafid partition could probably arise from stresses working on the complex texture of an accretional earth. Besides, certain definite tendencies to inequality of development appear to have arisen as the segmentation went on. There was the law of progressive dominance. Whenever in the course of growth, any division came to preponderate in mass or density, this very preponderance gave advantage in the acquisitions that followed. Dominance not only tended to its own perpetuation but to the increase of its own preponderance. It naturally resulted that some of the sectors grew more than the others. The basins of the southern hemisphere seem to have taken precedence of those of the northern, and the basins of the Pacific took precedence over those antipodal to them. These two preponderances united to give a preponderant water hemisphere, with its center near New Zealand, and a preponderant land hemisphere, with its center in southwestern Europe.

There was also the law of alternation. When any pyramidal sector sank from superior weight, it crowded aside the adjacent sectors, and the belts of easement between them were squeezed in proportion as adjacent basins sank. And so depressions and elevations alternate around the globe.

There was also the law of opposites. Whenever any pyramidal sector sank by reason of superior weight, it favored reciprocal rise on the opposite side. So, as a matter of fact, depressions stand opposite to embossments about the globe.

There was also probably an adjustment of the sectors relative to one another. Ideally, the sectors might stand point to point, but this is an unstable adjustment, and amid the inequalities and distortions that arose, the sectors would naturally be shifted in the direction of least resistance, so that the sinking heavy sector, on one side, would come to stand opposed to a yield tract on the antipodal side. And so basins should have come to be antipodal to protrusions, if not already so at the outset. In harmony with this, it may be observed that the North American embossment stands opposite the basin of the Indian Ocean, the Australasian embossment opposite the basin of the North Atlantic, the great east central basin of the Pacific opposite the great protuberance of Africa, the South Pacific opposite Asia in part, the Antarctic continent opposite the Arctic basin, while the great oceanic sag around the Antarctic continent stands over against the great land belt in the high latitudes of the northern hemisphere.

There are a multitude of interesting details and qualifications, and some incongruities, upon which it would be delightful to dwell were there time. In the very tentative and imperfect presentation of this doctrine which alone is possible here, let us content ourselves with the merest glance at certain salient illustrations of the suggested segmentation of the earth.

Starting with the hemisphere of heaviest segments and largest present increments—which therefore probably took precedence in action—the three oft-noticed poleward-pointing extremities of Africa, Australia and South America illustrate the three-fold division of the polar region, in fair harmony with the terms of our interpretation. Following the South American axis northward to the vicinity of the fulcrum zone, the ideal scheme demands bifurcation and angulation. In harmony with this, marked structural features diverge to the northwest and northeast. The former strikes through the Isthmus of Panama, the states of Central America—with the Antilles as a duplicate line—and onward to the vicinity of the fulcrum zone of the northern hemisphere, where the dominant structural lines should turn in a second angulation, toward the north pole. This is partially realized, but is much obscured by superimposed features that cannot here be discussed.

Turning back to the point of bifurcation in South America, "the Backbone of Brazil" strikes northeasterly, and, save for the interruption of the constricted connection between the two Atlantics, is continued in the structural lines of northwestern Africa to the critical zone of angulation on the borders of Africa and Europe.

Turning back again to the south African axis, it is to be noted that, near the proper latitude for bifurcation, two ancient crystalline terranes diverge in lines nearly parallel to the borders of the continent, and extend across the equatorial belt to about the assigned zone of angulation in the northern hemisphere, where converging deflections toward the north pole are encountered, notably the west border of Europe and the Ural mountains.

Both Australia and New Zealand have southern prolongations that seem to represent, in a duplicate way, the third meridional easement tract of the south polar regions. At about the assigned latitude, a broad strand of northwesterly trending structural lines run through the East Indies and connect Australasia with southeast Asia. The trend of this remarkable strand is continued to the latitude of the northern zone of angulation where a complex series of divergencies is encountered with a northerly and northeasterly trend.

In perfect symmetry and completeness obtained, there should be three main yield tracts from the poles to the fulcrum zones not far from 30° Lat. N. and S., while between these there should be oblique trends. At the same time, the great continental embossments and the great abysmal basins of the two hemispheres should stand in alternate or offset positions relative to one another. These basal requirements of the interpretation should be rather distinctly discernible, though much obscured by outgrowths and distortions. The North Atlantic should be offset to the west relative to the South Atlantic, North America relative to South America, the North Pacific relative to the South Pacific, Asia relative to Australasia. These radical requirements are strikingly realized. North Africa and Europe are less strikingly offset relative to South Africa, but the tendency is marked. The obliquity of the trends in the equatorial belt is strikingly displayed in the East Indies, and in the West Indies and isthmian connections between the Americas. It is betrayed also in the trends of the singular physiographic features that affect the junction area of Africa, Asia and Europe.

Time will not permit us to lapse into explanatory details. The scheme of interpretation only calls for the detection of a deeply buried embryonic framework on which other agencies have built the adult configurations of the globe, and on which they have imposed their own characteristics.

Dynamic Organization of the Atmosphere

The working relations of the primary segmentation of the earth-body to the dynamic organization of the atmosphere, were close, both in causation and in effect. There were striking analogies between them. The broadest features of the atmospheric circulation are now, and probably were in the earth's juvenile stage, as simple as the broad features of rotational deformation. So too, the secondary adjustments of the atmospheric circulation in the two hemispheres are now, and probably were from the outset, very similar to the secondary adjustments of the earth-body. All the significant features of this analogy can not even be mentioned. We can simply note that, over the great oceanic basins in the latitudes of the fulcrum zones, there are oval systems of circulation centering about the areas of high atmospheric pressure, which match, in a general way, the centers of high specific gravity in the basin sectors below. On the borders of these ovals, there are tracts of conflict and of high precipitation, corresponding to the disrupted adjustment tracts of the earth-body below. These gyratory systems and these tracts of precipitation influenced fundamentally the deposit of planetesimal dust, and thus gave direction to the growth of the earth, while, at the same time, they themselves were profoundly influenced by the configuration of the earth-body, and by the waters gathered into its great basins. And so the three great factors, atmospheres, hydrosphere, and lithosphere, cooperated in building up and giving shape to the great features of the earth.

It is obvious that whatever planetesimal material found lodgment on the lands was subjected to greater leaching than the portions that fell into the waters. It appears that the average specific gravity of the elements leached away must have been slightly higher than that of the portions left behind—in the form they would finally take after burial and metamorphism—so that the protuberances came to be formed of slightly lighter material than the basins, and hence, in deformative actions, the basins took precedence in sinking and the continents were accommodated to this. This contributed to the permanency of the great features of the earth which, in turn, influenced the atmospheric circulation.

We find then, in this mechanism, reasons for the observed lower specific gravity of the continents and the higher specific gravity of the sub-oceanic material. In this, also, lie reasons for the continuous maintenance of the continents, and hence the perpetuation of continental life, as well as the reciprocal maintenance of shallow-water oceanic life. Some of the greatest generalizations of geology thus find inherent support and adequate elucidation in the very origin and constitution of the continents and of the ocean basins, while in this inherited constitution

are found cogent reasons why these great features are, and should ever remain, protrusive and depressive, respectively.

We are thus brought to conditions that are fundamental to the evolution of life on the earth. This fascinating theme I must leave to my successor. It is to be noted, however, that the physical evolution of the earth predetermined, in large measure, the lines along which the life evolution of the globe was compelled to proceed.

When the great embossments and the deep basins had become determinate, and when the earth's growth had been completed, there followed a long history of denudation of the land, of filling of land-girt basins, and of building of terraces about the borders of the lands. There were base-levelings and great transgressions of the seas, covering sometimes half the continents, but never, in the known history of the earth, wholly submerging them. Before complete submergence was reached, rejuvenation intervened; the continents were re-elevated and the seas withdrawn by further sinking of their basins, and a new period of life evolution ensued. The whole sea-history seems to have been a succession of encroachments followed by retreats, with correspondent expansions and restrictions of sea life, while the land areas were reciprocally reduced and expanded with corresponding restrictive and expansive evolutions of land life. Thus the familiar evolutions of the well-known history of the globe went forward controlled, in a profound way, by the hidden powers of renewal inbred in the early organization of the earth-body. The whole evolution was, at the same time, profoundly influenced by the constitution of the atmosphere and by climatic conditions.

The Evolution of the Atmosphere

The evolution of the atmosphere under the older cosmogonic views took the form of a great decline from a vast primitive envelope through a long series of depletions, to the relatively emaciated conditions that obtain to-day, under this interpretation. All this is too familiar to need more than simple reference. The alternate view here entertained pictures the atmosphere as growing up from small beginnings and maintaining itself throughout the ages by alternate enrichment and depletion from within and without. A bare sketch of some of the least familiar of these tenets is all that can be given.

The lower atmosphere is eminently collisional, each molecule colliding with other molecules with prodigious rapidity. This condition prevails upwards until the tenuity of the air becomes so great that molecules, bounding upward from encounters, find no other molecules in their path until gravity has had time to arrest them and draw them back toward the earth center. There are thus substituted vaulting leaps for to-and-fro motions. A fountain-like zone supervenes upon the the collisional atmosphere. This krenal atmosphere is necessarily very

attenuated, but the vaulting molecules do not entirely escape collision with one another. From these mid-vault collisions rebounds, more or less tangential to the earth, arise in a certain proportion of cases. Under the law of probabilities, a certain percentage of molecules thus rebounding have sufficient velocities to take orbital courses about the earth. When they have once entered upon these orbital courses, molecules may remain indefinitely in them, if not driven from them by some intervening agency. This introduces a distinctly new factor, for this permits accumulation to go on until this very accumulation checks itself. The logical series consists, therefore, in a vaulting ultra-atmosphere, springing necessarily from the summit of the collisional atmosphere, and, in turn, giving rise to an orbital atmosphere which must tend to accumulate until an equilibrium is reached, in which the orbital atmosphere gives back, or throws outward, as many molecules, in the long run, as it receives.

Now a limit to the outward extent of the vaulting molecules and of the orbital molecules is found in the limits of the sphere of the earth's control. The minimum radius of this, according to Moulton, is a million kilometers (620,000 miles), the maximum radius, a million and a half kilometers (930,000 miles). Under kinetic laws there seems no logical escape from the conclusion that a certain proportion of molecules vault to the limit of this sphere of control and beyond it, and that orbital molecules occupy, in their extremely attenuated way, the whole of this sphere also. Those molecules that pass beyond this sphere enter the sphere of the control of the sun and are lost to the atmosphere of the earth.

Similar logic applies to the ultra-atmospheres of the sun whose sphere of control envelopes the earth. The sphere of control of the earth has been sweeping through the sphere of control of the sun throughout the entire history of the earth. As a result of these relations, it is logically inferred that there has been a feeding in of molecules from the sun's ultra-atmosphere, during the whole evolution of the earth, and that these exchanges have tended toward an equilibrium by which the scanter atmosphere, whichever it may happen to be at any stage, has been fattened by the richer atmosphere. Logically this relation obtains to-day. .

If this interchange were solely dependent on mechanical action between the molecules, its quantitative sufficiency might possibly be open to question, but this interchange is the basis for cooperative action by electric and magnetic agencies. The competency of these, while as yet undetermined, is very probably important. Electric and magnetic actions not only abet the mechanical distribution, but offer possible, if not probable, solutions of the grave problems that arise respecting a constitution of the early atmosphere suitable for the generation and

maintenance of terrestrial life. It is a notable fact that the actively combining molecules of the earth's atmosphere belong to a special class which have a general tendency to bear a negative charge of electricity, among which the vitally essential element oxygen is chief.

Functions of Oceanic Circulation

The superficial circulation of the oceans is a result of the winds, but the deep circulation appears to be the product, in part, of the differences in density of the sea water. At present, two great influences seem to be contesting for the mastery of the deep sea circulation, and, through such dominance, for the mastery of our coming climate. The dominant circulation is now controlled by the polar regions, especially by the Antarctic. The density of the sea water is there increased by low temperature and by some concentration of salts through freezing. With this higher specific gravity, the polar waters outweigh the warmer waters of the lower latitudes and descending flow along the ocean bottoms into the depths of the abysmal basins, rising ultimately in the equatorial tracts to depress the temperature there and to force the heated waters poleward. This deep-sea circulation is, without doubt, one of the elements that perpetuate the semi-glacial conditions of our times. Over against this, is the work of evaporation in the arid tracts, notably the 30° belts. By such evaporation, the waters of the Mediterranean are distinctly higher in specific gravity than those of the Atlantic and, as a result, the dense, though warm, saline water flows out through the Straits of Gibraltar into the Atlantic, spreading out in spatular form nearly across the North Atlantic, and descending to great depths. Similar dense waters flow out from the Red Sea, while under the great evaporating belts analogous condensations are taking place, the effects of which are felt to very notable depths. It is not known whether this increase of density in the warm tropical regions is gaining upon the density-effect of the polar regions or not. We must wait for future observations to decide how the battle is going. But it is clear that if the intensities of polar cold were mitigated, as in time they no doubt will be mitigated by the wearing down of the heights of the land and by the encroachments of the sea, there is reason to believe that the density which springs from evaporation in the low latitudes will gain the mastery over the polar water, and will sink to the bottom of the sea, filling the basins with warm water. This heated water creeping to the polar regions would carry warmth where now there is frigidity, a natural water-heating system of a stupendous sort. This seems the most probable explanation of the extraordinary fact that throughout the larger portion of earth history, so far as we are able to decipher it, mild climates, even sub-tropical climates, have prevailed in high latitudes, notwithstanding the adversities of their long winter nights, so notably

devoid of heat from without. It seems probable that the conditions which favor the dominance of polar cold, at intervals, and the dominance of tropical warmth, in the longer periods between, is determined by the elevation and the configuration of the land, especially that in the polar regions. The present cold oceanic circulation is known to be dominated by the Antarctic Continent and perhaps sprang initially from the geologically recent elevation of that continent. As it shall be cut away by the wear of the surface and the gnawing of the sea, its dominance will no doubt disappear and the dominance of tropical circulation take its place.

Correlated with these temperature changes of the oceanic waters are atmospheric absorptions and interchanges of gaseous content of a vital nature upon which time forbids us to enter.

Projecting these interpretations of the present oceanic junctions back through the geologic ages, they seem to imply successive alternations of remarkable warmth in high latitudes and glacial cold in relatively low latitudes, and corresponding climatic stress effects on life evolution and life distribution.

This system of interpretation assumes that the atmosphere has been maintained from the beginning of the earth's mature history in a state of approximate equilibrium with the atmosphere of the sun; hence an essential uniformity in volume and in constitution have been preserved unbroken from the dawn of life to the present. At the same time, it is held that, subordinate to this essential uniformity and this equilibrium, there have been notable fluctuations in volume and in constitution, due to variations in feeding from the interior of the earth, variations of depletion by chemical interaction with the rocks, and variations in the degree of absorption into the hydrosphere. The atmosphere has been subject also to variations in the retention of solar heat—the essential factor in climate—due not only to variations in constitution, but to variations in the intensity of vertical circulation promoted by surface features. Out of combinations between this automatic regulation of the fundamental constitution of the atmosphere and the oscillations of terrestrial conditions that arise in succession, spring, we think, the essential features of the evolution of the earth's climate, so far as they are terrestrial at all.

Thus far I have tried to emphasize the more fundamental of the dynamic agencies that seem to me to lie back of the physical evolution of the earth. Until the whole history of the earth, early and late, shall be worked out into an accepted interpretation, the *reasons* for the interpretations we entertain are quite as vital as the interpretations themselves. The breadth of the theme has made imperative a most cruel and partial selection. I think I may assure myself that no one else will fully justify the partiality of the selections I have made. It has

seemed to me, however, more vital to dwell upon the genetic and the fundamental, than upon the more declared features of the record. These are better deployed, relatively, in the literature of the earth-sciences, and are accessible in our ampler texts. They are the common ground on which we all unite, with more or less complete unanimity.

In a closing sketch of the accepted eras of the earth's adult history, it will be possible to touch only on a few high points. Our scant selection can be justified only by frankly affirming that there are other high points quite as worthy of emphasis.

Great Eras of Earth History

The lowest accessible record is found in a great complex of crystalline rocks whose metamorphism has somewhat obscured their original state. An essential portion of the complex terrane is the work of its own time; the rest was intruded at later dates. The primitive portion carries clear evidences that it was formed at the surface by sedimentary processes, eolian, aqueous, igneous, or pyroclastic. But this portion has been so much intruded, or traversed, by lavas escaping the pressures of the interior, that this immigrant factor obscures and, in some degree, masks the prior sedimentary element. It is to be noted, however, that all subsequent effusions of lava traversed this basal series, and so added to its complexity, and that it was affected also by all the later deformative actions. None the less, eruptive action seems to have been more prevalent in these Archean ages than in those that followed. In its earliest adult stage, the fires of youth seem yet to have been specially active, and the master events seem to have centered about igneous and metamorphic action—but it would be a serious error to overlook the vital contribution that the atmosphere and the hydrosphere cast into this, the earliest of the accessible lithographic records. There are signs of life, but they reveal little of its nature.

There followed this basement complex, a series of great terranes in which the dominant elements were more declaredly the products of aerial decomposition and of aqueous erosion, assortment, transportation, and deposition, though here the igneous factor cast in a very notable contribution also. There are left few identifiable relics of life, but there is abundant evidence of organic action. Between this Proterozoic group and the underlying Archean, lies a great unconformity, and within the group itself there lie scarcely less great unconformities, all of which imply that great movements intervened between times of relative quiescence, a feature that ran through all subsequent history. Even in this early age, there are signs of glaciation in mid-latitudes and apparently at moderate elevations (Coleman), a feature of vital significance in the interpretation of the climatic history of the earth.

Following another great interval, marked by unconformity, the

Paleozoic Era was ushered in, and with it the first good record of the specific forms of life. The feature of supreme interest, the first good record of life, falls to the lot of my successor, who will give its interpretation and sketch the subsequent life evolution. During the Paleozoic Era there was a series of relatively quiescent periods during which the joint forces of the atmosphere and the hydrosphere made great progress in cutting away the protuberances of the continents and depositing the débris in great sub-sea terraces about the continental borders and in the infra-continental basins, thus partially base-leveling the land, and partially filling the basins, so that the ocean waters crept forth on the borders of the land and seemed to threaten complete submergence. But rarely was more than half the continent conquered before internal stresses had accumulated in sufficient force to bring on another epoch of deformation and continental protrusion, pushing up the land and pushing back the sea, restoring in a measure the old status and preparing the way for a new sea-transgression. After some half dozen periods of such oscillation, a more marked series of deformative movements ensued, with a more pronounced rejuvenation of the land. With this came also the most remarkable of all known glaciations. Mantles of ice gathered on lands near the circles of Cancer and Capricorn and left distinctive records which, however seemingly incredible, are incontestible. To add to the seeming strangeness, the evidence clearly points to low altitudes of the land and to the descent of the land-ice into the waters of the sea which bore icebergs to long distances and formed extensive glacio-natent deposits. That the great deformative action had some genetic relation to this remarkable climatic episode, seems eminently probable, but it does not seem to have accomplished this directly by the elevation of the sites of glaciation.

These remarkable events ushered in the Middle Ages of geology—as much a misnomer as the Middle Ages of human history—the early stages of which seem to have witnessed the greatest extension of land, and apparently the greatest general aridity of climate, known to geological history. But, in time, the persistent gnawings of the atmosphere and the hydrosphere—geologic twins in never-ceasing activity—cut down the great embossments and permitted the sea to transgress the land repeatedly before the Mesozoic Era closed. But, as ever before, the land persisted and was periodically renewed. After fewer oscillations than in the Paleozoic Era, another notable epoch of diastrophism intervened, and the Cenozoic Era was inaugurated. Glaciation seems to have recurred in mid-latitudes (Atwood), but the evidence is as yet less ample than in the preceding transition.

After a shorter succession of base-levelings and sea advances, separated by minor rejuvenations of the land, there came the recent great series of deformations which gave rise to the present great folded moun-

tains, the present great plateaus, and the special configurations which the continents and oceans now bear, save in relatively trivial details. Close on the heels of this great diastrophic epoch came on the last great glaciation in mid-latitudes. At that time, ice-sheets crept down on the American plains to the Ohio and Missouri rivers, and over the northern plains of Europe, while in the southern hemisphere and on mountain heights, even in the tropics, there were signs of a general depression of temperature. There were repeated advances of the ice-sheets, separated by milder intervals during which retreats took place, showing, even in such episodes, the tenacity of the principle of oscillation in terrestrial ongoings. It is only recently, geologically speaking, that the ice-sheets have retreated from the lands where half the civilized world now lives. Glaciers linger in the polar fields and on the mountain heights. The deep sea is still icy cold. The contrasts of climate are sharp. We seem to be yet in the cold segment of the climatic cycle. Whether we are about to emerge into a period of typical mildness, or are yet to suffer a recurrence of the ice invasions, is a geologic detail beyond safe prophecy, but that such emergence is to follow, sooner or later, seems assured by the long history of oscillations of the past and the persistence of recovery that seems to be firmly based on the automatic regulation of the atmosphere and of climate inbred in the very constitution of the earth.

PROBLEMS ASSOCIATED WITH THE STUDY OF CORAL REEFS. III

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Upgrowing Reefs in a Rising Ocean.—Are we then to regard Darwin's theory of subsidence as completely established? Not yet, for there are two alternative theories that have not been mentioned. It has already been pointed out that all the visible features of sea-level reefs themselves, apart from the neighboring volcanic islands, can be equally well explained by any one of some eight or nine hypotheses, provided that the postulates of the hypotheses are accepted; and that appeal must therefore be made to some associated problem in order to find a crucial test by which the true theory can be selected. Let it now be recognized that all the features of barrier reefs and of their embayed central islands also, which according to Darwin's theory are explained by the subsidence of the reef foundation beneath a stationary ocean surface, can be equally well explained by supposing the ocean surface to rise over a stationary reef foundation, as in Fig. 30. It is only by appeal to certain rather recondite associated problems regarding the rest of the world that this second possibility can be excluded, and the first fully justified.

In discussing this aspect of the problem we must recall at the outset that an adequate theory of coral reefs has to account, not only for the last touches given to existing sea-level reefs, but also for their relatively remote beginning; that it has to explain not only sea-level reefs, but also elevated reefs, formed in an earlier epoch and now standing hundreds of feet above sea-level; that it has to provide reasonable conditions for the great submergence indicated by the deep embayments of Kandá-vu, Tahaa, and many other islands; that it has to account for the occurrence of small remnants of large volcanic islands within large reefs; and that it has to explain the heavy limestones in such uplifted atolls as are found in the Loyalty islands and elsewhere, as well as the thin terracing reefs that are uplifted in the New Hebrides. In short, an adequate theory of coral reefs involves great and small terrestrial changes such as will cause great and small submergences and emergences at different dates in the later ages of the earth's history. If we account for all such changes, not by local subsidence of the reef foundations, but by changes of the sea surface caused by deformation of some

other parts of the sea floor, we must postulate repeated crustal movements of so enormous a measure that they become improbable to the point of incredibility; for it must be remembered that whenever the sea surface is to be raised 1,000 feet by upheaval of a part, such as a tenth, of the sea floor, that part must be upheaved at least 10,000 feet; and more than 10,000 if, as is very probable, its upheaval is accompanied by a contemporaneous depression of some neighboring part. It is therefore consistent with terrestrial economics to account for the great submergence which coral reefs demand by subsidence of the needed amount in the area where and at the time when the reefs are formed.

Furthermore, if the submergence indicated by coral reefs and their associated islands be explained by a rise of sea level, let it be remembered that this requires the submergence to be everywhere—on all continents and all islands—the same in rate, date, and amount, except where local crustal movements introduce variety into its measure. In view of the apparent variety in the date and amount of submergence by which existing embayments of insular and continental shorelines have been formed, the appeal to local movements as a cause of the variety may be so frequent that such movements will become the dominant control of submergence, each in its own region. Indeed the explanation of all coral reefs by a rise of sea level recalls the explanation given by Suess, about thirty years ago, for all high-standing atolls by a general depression of sea level; as soon as the diversity in the altitude of such atolls is recognized, their position must of course be explained by diversity of crustal movement rather than by a uniform change of sea level: so, I believe, when the submerged embayments of the world's coast lines in coral-reef regions and elsewhere are attentively examined, and when the emerged coastal plains of certain continental borders are closely studied, many diversities in the rate, date, and amount of their submergence or emergence will be discovered. Such diversity will then be best explained by local crustal movements, and world-wide changes of sea level will be given relatively small values.

But let me state explicitly that it would be highly illogical to exclude so manifestly possible a factor as a universal change of sea level from all share in submerging shoreline embayments or in laying bare strips of coastal plains; it is because any change in sea level must be smaller than the uplift or depression of the sea floor which causes the change in the same proportion that the uplifted or depressed area is smaller than the total ocean area, and because the sea integrates all the positive and negative changes which various local movements tend to produce in its surface level, that it seems most reasonable to explain regional submergence, long continued in time and great in amount, such as that involved in the origin of many coral reefs, chiefly by subsidence in the region and at the time concerned.

The Glacial-Control Theory of Coral Reefs.—There is one phase of the theory of a rising ocean, pointed out by several writers in the last thirty or forty years and lately discussed more fully by another, that demands further examination. This is the idea that the drowned-valley embayments, which we have been taking as signs of subsidence, have been submerged by the rise of the ocean surface as the water, which was abstracted to form the continental ice sheets of the Glacial period, was returned to the ocean when the ice sheets were melted in the milder climate of Postglacial time. This in its fully developed form has been called the Glacial-control theory, and its discussion evidently involves many associated problems besides those already mentioned. Its essential postulates and processes are as follows: Coral-reef flats are supposed to have been formed around or upon still-standing foundations in Preglacial time, hence presumably for the most part by outgrowth; the ancestors of atolls, now the commonest kind of reefs, were formed around volcanic islands that had stood still long enough to be worn down by subaerial erosion nearly to sea level or by marine abrasion a little lower; the ancestors of barrier reefs were similarly formed around islands that are not old enough to have been worn down; lagoons were shallow or wanting, because solution is not an adequate cause for them. As the Glacial period came on, the surface of the ocean was lowered by the imprisonment of a large volume of water as ice on the lands; it has been calculated that the lowering of the entire ocean thus caused was between 200 and 300 feet. The ocean was then chilled as well as lowered, and thereby the corals of most reefs were killed. The waves of the lowered sea attacked the undefended flanks of the dead reefs and cut them back in flat platforms. Next when the climate became milder and the ocean surface rose again, reefs were reestablished and grew upwards on the platform edges of the earlier reef flats, and thus the barrier and atoll reefs of to-day have been built up around the lagoons that they enclose. It thus appears that the Glacial-control theory accounts only for the reef rims and the lagoons of atolls and barriers, and that the great undermass of the reefs is explained according to the theory of outgrowing reefs on still-standing foundations, but without the action of solution in the excavation of the lagoon.

All the causes here mentioned appear to be true in quality, but their quantitative value is uncertain. The oceans must have been lowered and cooled during the Glacial period, but no one knows how much. The corals of reefs that had grown in Preglacial time on the northern and southern borders of the coral zone, as around the Hawaiian islands, were presumably killed; but it is impossible to say, *a priori*, whether the corals were killed through the middle of the torrid coral zone as well. Dead reefs must have been attacked by the sea below their crown, but who can say how far they were cut away? Live reefs would not

have been cut away. Additional factors are introduced by the complexity of the Glacial period, for it includes several Glacial epochs of different intensities separated by Interglacial epochs of different durations; and no one yet knows how to date the history of coral-reef islands in terms of Glacial chronology. The quantities involved in the Glacial-control theory are therefore of uncertain value.

Uncertainties of the Glacial-Control Theory.—There are two other groups of uncertainties in the Glacial-control theory, as it has thus far been set forth. The first arises from the improbable nature of one of its fundamental postulates; the second, from the over-long series of deductive steps—not always sharply defined—for which no sufficient verification has been provided by confronting them with observable facts. The improbable fundamental postulate is that the ocean bottom did not subside in the coral-reef region for a long period of Preglacial and Glacial time. No reasons are offered in support of this singular assumption; yet it is held to be so true that ancient volcanic islands, possibly formed as long ago as in Paleozoic time, are believed to have suffered flat truncation by erosion and abrasion, down to or a little below sea level, and that the flat surface of truncation remained close to sea level, without subsidence, until the Glacial period! Is it not venturesome to give subsidence the special value of zero for so long a time in the coral-reef region of an ocean, the bottom of which has suffered repeated elevations, as shown by uplifted coral reefs, and has suffered, in its Australasian area, demonstrable deformation, with many ups and downs, as shown by the isolated remains of former continental lands? And is it really necessary to make subsidence zero for a long time and over a large area in a theory in which the occurrence of subsidence now and again at a slow rate or by starts and stops is not at all incompatible with the various processes of Glacial control, even though it would affect the value of their results? Yet as stated by the latest expositor of the Glacial-control theory, this unnecessary and venturesome postulate is practically insisted upon, and the theory is therein made to resemble the several other theories that arbitrarily postulate still-standing islands, and thus place themselves in opposition to Darwin's more general theory of subsidence: "more general," because subsidence can have all grades of value from its maximum down to zero, and because prevailing subsidence may be interrupted by still-stand pauses or even temporarily reversed into uplift, as Darwin clearly stated; but still-stand theories are based on a rigidly fixed postulate of immobility, as far as subsidence is concerned.

Among the unverified deductive steps in the Glacial-control theory, we may note in particular the Preglacial truncation of numerous still-standing volcanic islands at sea level or a little lower; the Preglacial formation of numerous marginal reefs by outward growth on an ad-

vancing talus of coral débris around still-standing truncated flats or shoals; the reduction of ocean-surface temperature in the coral zone during the Glacial period sufficiently to kill the corals of nearly all reefs; the complete abrasion of even the broadest atolls during the lowered sea-stands of the Glacial period; the uncomformable upgrowth of new atoll reefs on the abraded platform of low Preglacial islands as the sea rises; and again, the Preglacial formation of outgrowing encircling reefs around younger, mountainous, still-standing, non-embayed volcanic islands; the reduction of these reefs to platforms by abrasion during the lowered sea-stands, but without significant encroachment upon their central islands; the erosion of the deeper parts of the central-island valleys, now drowned in embayments, during the lower sea-stands of the Glacial period, but to no greater depth than the level of the lowered sea; the sufficient widening of the deepened valleys by the slow process of valley-side weathering during the lowered sea-stands, so that, when drowned, the valleys shall contain the well-opened embayments now visible; and the unconformable upgrowth of new barrier reefs on the abraded platforms with the rise of the sea.

No sufficient verification is provided for this elaborate series of deductions. Not a single example of a truncated volcano is known in the coral seas. Not a single example of a recently uplifted atoll is known to have an abraded volcanic area in the center of its lagoon-plain. Not a single example of an uplifted atoll is known to consist in its underpart of the steeply inclined talus layers composed chiefly of coral débris, such as must here be supposed for the great undermass. Not a single example of a recently uplifted atoll or barrier reef is known in which the reef wall stands unconformably on a flat platform abraded across a series of slanting talus layers largely formed of coral débris, as must be the case under the Glacial-control theory. True, an attempted verification of the abrasion of Preglacial atolls during the lowered sea-stands of the Glacial period has been offered in a table of the depths of atoll lagoons; but the measures of depth show no such accordance as the theory demands. The maximum depths of the lagoons vary through a large fraction of the supposed depth of the abraded platform; the mean depth of the deeper parts shows a similar variation. Such inconstancy of lagoon depth can be explained only by supposing that the atoll platforms were abraded at various levels, for which no good reason is assigned; or by supposing that the platforms, after being abraded at a uniform depth, have been irregularly covered by Postglacial lagoon deposits. The latter supposition is extremely probable, as far as the occurrence of lagoon deposits is concerned; but if accepted it leaves the platforms without verification. It may be truly said, in reply to this and the preceding paragraph, that all theories of coral reefs, the subsidence theory as well as the rest, involve unverified deductions; but as far as I

can see, the subsidence theory is less deficient in this respect than any other.

In view of the insufficient attention that, as thus appears, has been addressed to the matter of confrontation and verification in the Glacial control theory, in the form in which it has thus far been set forth, it seems desirable to give closer examination to that phase of the problem; not with the intention of making up the deficiencies in the statements of its expositors, for that is their own affair; but with the wish of finding for oneself definite grounds which shall warrant a decision in favor of the theory or against it; for it is the duty of every investigator to make himself personally responsible for the critical discussion of every theory that has been offered in solution of his problem; he must not

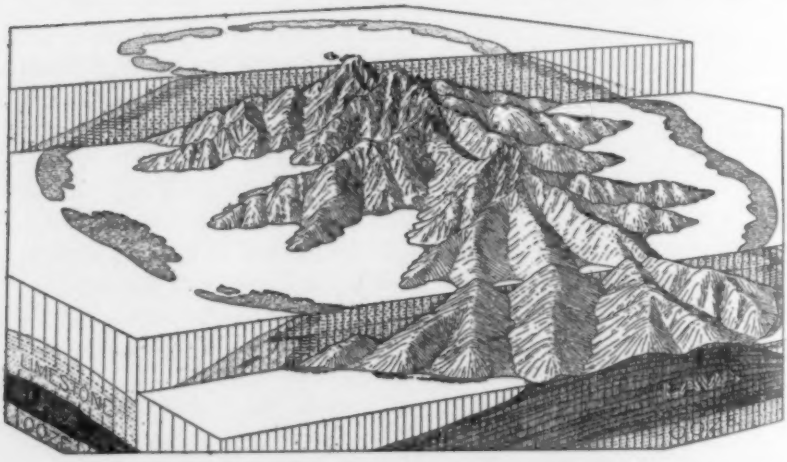

FIG. 30. BLOCK DIAGRAM OF A STILL-STANDING VOLCANIC ISLAND IN A RISING OCEAN. In the narrow foreground block, the island has a simple shore line with a discontinuous fringing reef; in the middle block, the rising ocean has half-submerged the island, giving it an elaborately embayed shore line, and the fringing reef has developed into a barrier reef by up-growth; in the background block, the rising ocean has almost submerged the central island, and the barrier reef has almost become an atoll. The first up-growth of the fringing reef, as shown on the front face of the middle block, is drawn nearly vertical, because the amount of waste taken from it to form its short external talus was then small: the effect of a pause in the rise of the ocean is shown in the horizontal out-growth at mid-height in this section. The later up-growth of the barrier reef, as shown on the front face of the background block, is drawn inclining inward, because a large amount of reef waste is needed to form the greatly prolonged talus, which now begins at a greater height and must extend down nearer the base of the volcanic cone. Compare this figure with Fig. 16.

throw off that responsibility, or leave it wholly to the inventors of other theories than the one to which his judgment inclines. The first step to be taken in meeting this responsibility with regard to the Glacial-control theory is to define more sharply certain consequences to which it leads; and in doing so it might be well, as above intimated, to give special attention to reefs near the border of the coral-reef zone; but as the

only reefs so located that I visited were on Oahu in Hawaii and along the coast of Queensland in Australia, this method of testing the theory will not be pursued for the present. The reefs of the torrid zone, of which I saw more abundant examples, will be examined instead; and for this purpose several tentative assumptions will be made, from each of which certain essential consequences will be deduced, in order to confront them with the facts.

Special Consequences of the Glacial-Control Theory.—For example, sector *E*, Fig. 31, represents a rather narrow Preglacial reef plain,

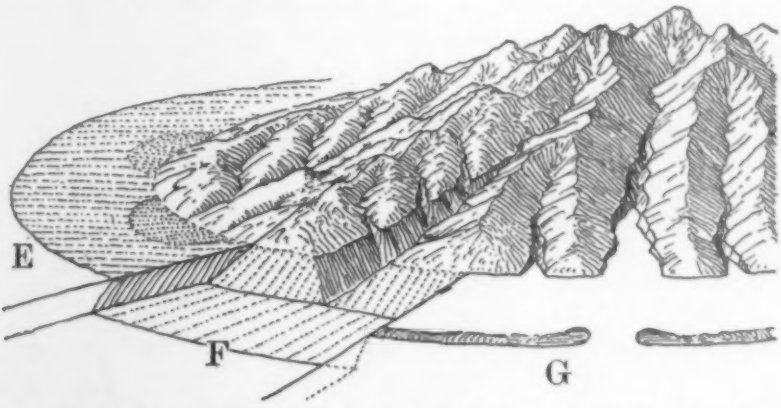

FIG. 31, DIAGRAM OF SUCCESSIVE STAGES OF REEF FORMATION, as deduced from the Glacial-control theory, on the supposition of a relatively short period of lowered ocean level.

with no lagoon, bordering a dissected, still-standing volcanic island of non-embayed shoreline and salient deltas. In sector *F*, we see the abraded platform cut by the waves of a lowered and chilled ocean, which did not, however, work long enough to becliff the volcanic island; and also a young valley incised with reference to the lowered sea level in the floor of a Preglacial valley. In sector *G*, the sea has risen and warmed, a barrier reef has been built up enclosing a lagoon, and the young valley is embayed. A detailed consequence of these changes is an "edge" where the steep walls of the young valley cut the gentler side-slopes of the Preglacial valley; this edge ought to begin close to sea level on either side of the new embayment near the former margin of the island, and gradually ascend inland beyond the embayment to the head of the young valley. No such edges, no such "valley-in-valley" forms were found in any one of the hundreds of partly drowned valleys that I saw in the Pacific; hence a second assumption must be tried. Sector *E*, Fig. 32, shows the Preglacial condition again; sector *F* represents the work accomplished during a longer time of lowered sea level than before, a time long enough to allow the widening of the new-cut valleys so that

all trace of the Preglacial valleys should vanish, even to their heads; but in so long a time as that, the sea would surely cut away not only all the Preglacial reef-plain, but part of the volcanic island as well; then, after the sea rises as in sector *G*, the spur ends between the wide embayments should be truncated, and the steep faces of their cliffs would plunge below sea-level. Cliffs of this kind ought to be specially well developed around the younger volcanic islands, which in Preglacial times had only narrow fringing reefs or no reefs.

But spur-end cliffs do not occur on such islands: hence the corals of their reefs cannot have been killed. Perhaps the drowned spur-end cliffs of Tahiti, figured above, are the work of abrasion during the lowered sea-stands of the Glacial period; but if they are, Tahiti is of so ex-

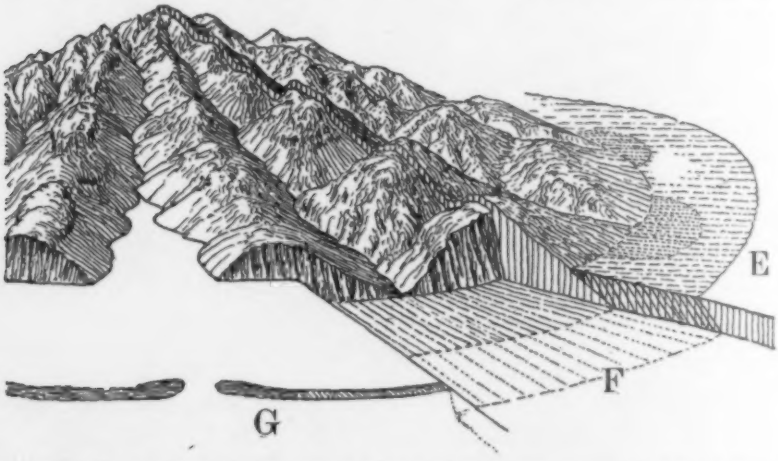

FIG. 32. DIAGRAM OF SUCCESSIVE STAGES OF REEF FORMATION, as deduced from the glacial-control theory, on the supposition of a relatively long period of lowered ocean level.

ceptional a form in this respect that its cliffs prove too much for other islands. The spur ends in the other members of the Society group and elsewhere are as a rule not cut off in cliffs; or if a little becliffed, a shallow platform extends forward from the cliff base, showing that the cliff has been recently cut at present sea level. Hence in order to explain the prevalently tapering forms of non-cliffed or little cliffed spurs, it must be supposed that the corals of their enclosing reefs were not killed while the sea was lowered, and thus an essential half of the Glacial-control theory, as it has been recently propounded, is excluded.

However, even if the corals were not killed and the reefs were not cut away, the valleys of the central islands must have been deepened while their streams ran down to a lowered sea level. But is it reasonable to suppose that the lowered sea level of the Glacial period en-

dured long enough to allow not alone the incision of narrow valleys by small streams, but also the widening of the valleys by slow weathering to the observed width of the actual embayments, some of which are one or two miles across? The simplest test I have found for this question lies in a comparison of the drowned-valley embayments of the volcanic islands in the Pacific with the valleys of certain dissected volcanoes in central France. According to French observers, those volcanoes are of Preglacial origin, and they have suffered glaciation more than once; but their valleys, even where enlarged by glacial erosion, have not consumed so much of their initial form as has been consumed in the embayments of Tahaa or of Borabora in the Society group, or of Ka-ndá-vu in the Fiji group, or of Rarotonga in the Cook group, or of Oahu in Hawaii; nor so much as has been consumed in the embayments of New Caledonia or of Queensland, which consist of continental, not of volcanic rocks. The valleys of the embayments in these islands are too wide to have been cut during so relatively short a time as the Glacial period; hence I am driven to think that the processes of the Glacial-control theory, acting alone, are incompetent to produce the observed results. Nevertheless the level of the sea must have been lowered during each epoch of the Glacial period, and must have risen in each Interglacial epoch as well as in the present Postglacial epoch. How can these undeniable changes be best included in a general theory of coral reefs?

Combination of Subsidence and Glacial Control.—The element of the Glacial-control theory which seems to me least reasonable is the postulate of still-standing reef foundations. Fortunately that postulate is unessential. Let us therefore see whether the Glacial-control processes and the subsidence processes cannot work harmoniously

FIG. 33. DIAGRAM OF SUCCESSIVE STAGES OF REEF FORMATION, as deduced from a combination of the glacial-control theory with Darwin's theory of up-growth during subsidence.

together. Sector *H*, Fig. 33, represents a barrier reef developed during Preglacial subsidence in a region where Glacial cooling, when it comes,

shall not be sufficient to kill the corals. Sector *J* shows the effect of continued subsidence without upgrowth in an unchanging ocean. Sector *K* shows the effect of neutralizing subsidence by the contemporaneous lowering of the ocean surface as the ocean water is withdrawn to form continental ice sheets; that is, if the island sinks at about the rate that the ocean is lowered, a relative still-stand is the result for the time being; and during a long enough still-stand a broad and mature reef plain will be developed by the outgrowth of the reef itself, by the inwash of its waste, and by the forward growth of deltas which will fill the former embayments and advance into the lagoon, as in Sector *K*. Now if subsidence continue during a maximum of glaciation, a critical condition will be reached when the ice sheets begin to melt and the ocean begins to rise, as in sector L, for the joint effect of ocean rise and subsidence will be a doubly rapid submergence, sector *M*, as a result of which the upgrowth of the reef may not keep pace with the rise of sea level, and the reef may become discontinuous; its renewed growth may even be stopped if it is "drowned" by too rapid submergence. Perhaps the discontinuity of certain reefs that rise, as has recently been pointed out, from submerged platforms, but not necessarily on their outer edge, may be explained in this way. In any case, I believe that some combination of regional subsidence with Glacial changes of sea level—or with changes of sea level caused by movements of the sea bottom—is worthy of careful consideration as being probably nearer the truth than either process taken alone: but of the several processes, subsidence in the coral-reef areas seems to me to have acted through a longer time and to have played by far the greater part in the development of coral reefs.

Other Hypotheses Regarding Coral Reefs.—Various other hypotheses have been proposed to account for coral reefs. Some of the early explorers explained reefs as determined by the instinct of the "coral insects"; others regarded them as built upon the rims of submarine craters; one long-practised student of the problem in more recent years suggested that an extensive system of barrier reefs near one of the larger Fiji islands may have grown up, independently of subsidence, from submarine lava flows; an observer in Samoa suggested that certain reefs in that island group have been determined by submarine hot springs; a widely experienced traveller in the Pacific suggested that many atoll-reefs are of small thickness, formed around uplifted and worn-down limestone masses of unexplained origin; a less experienced observer accounts for the outline of atolls largely by the action of wind-driven waves. These suggestions all represent conceivable possibilities; but they are not supported by sufficient evidence to show that they correspond to geological realities. The first of the six hypotheses is only a relic of an earlier philosophy; the second was generally accepted

till Darwin showed its impossibility; the third entirely overlooks the shore-line evidence of strong submergence following submature dissection; the fourth hypothesis makes the gratuitous assumption that submarine hot springs exist in requisite number and position; the fifth hypothesis includes no adequate explanation of the assumed limestone masses, although, where little dissected remnants of such masses are found, they have every appearance of being atolls of an earlier date; the sixth hypothesis exaggerates the action of a true cause, for it overlooks the usually concentric arrangement of central islands within their barrier reefs, as shown in Fig. 19; this arrangement demonstrates the action of winds and waves to be of secondary importance in determining reef outlines. Need these hypotheses be further considered?

Conclusion.—To what conclusion is an inquirer led by this study of coral reefs? At least to the certain conclusion that the origin of coral reefs, like the origin of many other geological features, is not susceptible of absolute demonstration. All that can be hoped for in problems relating to the past origin of present features, such as synclinal ridges in mountains of folded structure, hanging lateral valleys in formerly glaciated mountains, "faulted" strata, "metamorphosed" rocks, and coral reefs, is a highly probable explanation. It is true that geologists are accustomed to regard various highly probable explanations as having the same order of verity as directly observed facts: for who doubts that faulted strata, for example, have been displaced from their original continuity, or that fossils are of organic origin? Nevertheless, these universally accepted conclusions are nothing more than highly probable inferences. Why, then, are they universally accepted? Because the experience of many geologists through many years in many places gives every reason to accept them as correct, and as yet no reason to reject them.

No theory of coral reefs at present reaches so high a degree of probable correctness as to be universally accepted. It is true that most geologists of fifty or sixty years ago thought the coral-reef problem was fully explained by Darwin's theory of upgrowth during subsidence; but geological thought at that time was not so critical as it is now regarding the acceptance of hypotheses; and moreover the problem of coral reefs had not then been enriched by the invention of several alternative hypotheses. There was at that time practically only one theory of coral reefs before geologists worthy of consideration; it explained the things that it had been invented to explain, and that was deemed sufficient to ensure its correctness and to warrant its acceptance. In the last thirty-five years certain additional theories of coral reefs have been brought forward, all the theories have been subjected to closer scrutiny than before, and one or another of them has been accepted with more or less confidence by a less or greater number of geologists; but the majority of geologists,

disconcerted from the confident belief in Darwin's theory of subsidence that formerly prevailed, and demanding strong evidence before they accept any one of the several current theories, now have no definite views in the matter: they learn that the problem is "unsettled"; they have no opportunity of studying coral reefs themselves, and as a rule not time or inclination enough to make a close study of the work of those who have studied coral reefs. Such is the uncertain condition of the problem to-day. In view of this and as a summary of the fuller discussion on the preceding pages, the present writer offers the following statement of his own opinion regarding the several current theories as the result of much reading, observation, discussion and reflection during the past two years.

The origin of barrier reefs and atolls on still-standing islands more or less completely truncated by marine abrasion is contradicted by the features of the islands within barrier reefs and by the structure of uplifted reefs. The resurrection of this theory in recent years, after it had been shown by Darwin over 70 years ago to be incompetent as an explanation of barrier reefs, has not advanced the solution of the coral-reef problem.

The origin of atolls by upward and outward growth on still-standing submarine foundations capped with pelagic deposits is a manifest possibility, but it is not confirmed by any independent evidence. The theory is unfortunately limited by the unnecessary postulate of still-standing foundations. If this limitation be relaxed, and if, in view of the common occurrence of uplifted reefs in various parts of the Pacific, uplift is supposed to take place at a rate a little faster than the downward erosion of the uplifted mass and a little slower than the outward growth of the fringing reef, a conical coral island would result; the cone would be terraced if the uplift were intermittent; as erosion progressed, a volcanic nucleus would be disclosed. No such conical coral islands are known; hence uplift at the rate here suggested cannot have been commonly associated with the formation of atolls. But uplifted and little dissected atolls occur not infrequently as tabular islands; they show that rapid uplift sometimes occurs after the construction of an atoll is well advanced. Uplift therefore seems, when it acts, to be a more effective process than upbuilding.

If, on the other hand, in view of abundant evidence of subsidence that is found especially in the western part of the Pacific coral-reef area, intermittent subsidence is considered in association with the up- and out-growth theory of atolls, then this theory merges into Darwin's theory. If both uplift and subsidence are considered, it is evident that uplift is most favorable in the early stages and subsidence in the later stages of the process; for subsidence in the early stages would as a rule prevent the effective upbuilding of a submarine summit

by a pelagic capping, and uplift in the later stages would prevent the formation of normal atolls. Since normal atolls are to be counted by scores or hundreds, it seems, when all reasonable factors in their formation are considered, extremely improbable that many of them have been formed on submarine volcanoes that grew by eruption near enough the surface to be further built up to the coral limit by a pelagic capping, but did not grow by eruption above the ocean surface sufficiently to form enduring islands, and that, after their eruptive building had ceased, always stood still and never subsided. Indeed it would require extraordinary unanimity among pelagic volcanoes, in an ocean in which recent and subrecent eruptions are so numerous and in which signs of recent uplift and subsidence are so widespread and abundant, to build up a series of lofty cones from the deep ocean bottom, scores of which should approach close to the surface in regions now occupied by atolls, but none of which should form islands originally large enough to be still visible although much worn down, and none of which should suffer elevation or depression!

If more facts were known about atoll structures, some of the supposed possibilities above noted might be excluded; but as long as observation is limited to the surface reefs of atoll rings, their origin must remain a matter of speculation. Yet in view of what is known of other coral islands, the most reasonable result of speculation today must include subsidence as a factor in the making of many or most atolls.

The outgrowth of barrier reefs around still-standing islands, the excavation of their lagoons by solution, and the conversion of the barriers into atolls by the erosion and abrasion of their central islands is easily conceivable; but observation shows that lagoons are the seat of deposition, not of solution; no example of the almost-atoll stage, in which the central island of a barrier reef is reduced to a lowland with an alluvial rim, is known. The rigid fundamental postulate of still-standing reef foundations is contradicted by abundant evidence of changes of level, by the structure of certain uplifted reefs, and by the eroded surface of the volcanic or other rocks on which uplifted reefs rest. If the rigidity of this postulate is relaxed, and subsidence is allowed as demanded by various lines of evidence, a lagoon will be formed without the aid of solution, and the still-stand theory will be transformed into Darwin's theory.

The modification of the theory of outgrowth on still-standing foundations by the processes of the Glacial-control theory appears to be based on true factors, but unfortunately the quantitative value of these factors is unknown. The theory is ingeniously developed through a long series of deduced consequences, but it is arbitrarily limited by the unessential postulate of still-standing reef-foundations in the coral-reef region during a long period of time, and many of its consequences are,

as above noted, not confirmed by observation. The moderate abrasion of narrow-lagoon barrier reefs is, I believe, incompatible with the broad abrasion of large atolls; hence the corals of most reefs were not killed in the Glacial period. Many now-embayed valleys in barrier-reef islands are, as well as I can estimate, too wide to have been eroded during the Glacial period; hence their erosion must have been well begun at an earlier date when the islands stood at a greater altitude, from which they have since subsided. Thus the Glacial-control theory appears inadequate. If the unessential postulate of still-standing islands is omitted from the theory and the processes of Glacial-control are combined with those of Darwin's theory, as they well may be, the combination is a helpful one, especially along the margins of the coral zone.

It has been pointed out that all the consequences of Darwin's theory of upgrowth during subsidence may be accounted for by a contrasted theory, in which subsiding islands in an unchanging ocean are replaced by fixed islands in a rising ocean. It is entirely possible, nay, highly probable, that such replacement may have sometimes occurred; but it is extremely improbable that the replacement should be complete, for the following reasons. A moderate rise of ocean level over fixed coral-reef islands demands a great rise of a small part of the ocean bottom, or a moderate rise of a great part of the ocean bottom, always excepting the part where the fixed coral-reef islands stand; it demands also various movements of such other islands and continental borders as do not suffer submergence equally with the still-standing coral-reef islands: hence if the rising-ocean theory is to explain all coral reefs, it must demand that much or most of the earth's crust shall long be mobile, while the crust beneath the coral-reef islands must as long remain fixed. Such a demand is too absurd to be accepted. Moreover, if the rest of the earth's crust is so mobile, part of the ocean bottom outside of the fixed coral-reef region may sometimes sink, and the consequent lowering of the ocean's surface would be universally unfavorable to reef formation. Hence the rising-ocean theory can not be accepted as accounting for all coral reefs, and the part that it has played in accounting for any part of them must long remain uncertain. The uncertainty attending this theory is, indeed, so great that the theory is in danger of being discredited thereby: yet by nothing less than a world-wide observational study of coast lines can the uncertainty be resolved.

Darwin's theory of upgrowth during subsidence is not based on the rigid postulate of fixed reef foundations, but on the elastic postulate of a mobile earth's crust. It regards areas of subsidence as the most favorable for the growth of barrier reefs and atolls; it explicitly takes account of a possible variation in the amount of subsidence from place to place, and it as explicitly includes possible still-stand pauses and occasional moderate uplifts as interruptions in a prevailing subsidence.

Its processes are in no way inconsistent with those of the Glacial-control theory, for the two may be combined; its inferences as to extensive areas of ocean-bottom subsidence may be modified as new facts demand, without in the least invalidating its general value. True, the subsidence that it demands in certain areas is apparently to be measured in thousands of feet, and this seems formidable; yet objections to this demand are based much more on our ignorance than on our knowledge regarding the dynamics of the ocean floor. Hence Darwin's theory provides more general and more probable fundamental conditions for its following processes than are provided by any other theory. Furthermore, as far as present observation in the Pacific goes, nearly all the deduced consequences of the theory of upgrowth during subsidence are confirmed: unconformable contact of limestones in uplifted reefs on an eroded insular or continental foundation, instead of on a non-eroded foundation as is required by all the still-stand theories; observed or reasonably inferred large thickness of certain elevated reefs, instead of small thickness as required by the veneer theory; horizontal structure and rarity of fossil corals in the inner part of uplifted reef masses, instead of inclined structure and abundant fossil corals as the still-stand theories demand; embayed central islands within barrier reefs, the embayments being of such width and depth as no other but the very improbable rising-ocean theory can account for; steep but not becliffed islands of small size in the large lagoons of such barrier reefs as have almost reached the atoll stage; and lagoons of various depths, floored with accumulating deposits. So successful a confrontation of deduced consequences with observed facts is certainly very appealing.

Such is the array of evidence that has led me to regard Darwin's theory of upgrowing reefs on subsiding foundations as not only the most acceptable theory of coral reefs yet invented, but as with high probability the dominantly true theory of coral reefs. It is probably destined to be modified in subordinate measure as new facts come to light, and many new facts are without question still to be discovered; but it seems also destined to stand as the leading theory, even when thus modified. I therefore believe that Darwin's theory of subsidence will regain in this century the general acceptance it enjoyed through the middle of the last; and that the several alternative theories, which have found more or less favor in the last thirty or forty years, will be given minor rank or discarded altogether.

Retrospect.—The work of four men was often in mind during my Pacific voyage: Darwin and Dana of an earlier generation, Agassiz and Shaler of our own times. Nathaniel Southgate Shaler, my first teacher in geology, always my best friend at Harvard, the man who opened opportunity to me, who gave me encouragement and support when both were much needed, a man of ever-widening relations with his fellows,

in whose memory my journey across the Pacific is only one of many journeys that will be undertaken as the years pass. Alexander Agassiz, a man of varied and vast achievement, who saw and studied a greater number of coral reefs than any other scientific observer, and who gave all of us the great example of working untiringly to the end; but a man of so reserved a disposition that few of his associates knew him intimately. It is always a regret that my aquaintance with him was slight, and still more that I can not accept the conclusions to which he was led by his many journeys in coral seas.

Darwin and Dana, explorers of the Pacific nearly a century ago. How deep is the impress of these two men on the coral-reef problem! How inevitable is the mention of their names whenever coral reefs are discussed! But we must not picture the Darwin of coral-reef fame as a venerable old man, whose face, although wearied by work through long years of ill health, was always so patient and benign; nor yet as a man of middle age, who, steadfast against a flood of prejudiced criticism, opened new fields for thought and changed the philosophy of an unwilling world; but as a diffident youth, who, when some one was wanted to do scientific work on a long sea voyage eighty years ago, offered his inexperienced services for what they were worth, and yet carried with him such a fund of original thought that, while still in South America, he invented the best of all coral-reef theories before he had ever seen a true coral reef. And the Dana, who, younger than Darwin by four years to a day, followed him across the oceans, was not the grand figure who was still with us, so bravely alert in well-conserved erectitude, hardly more than a score of years ago; nor yet the man in middle life who, setting us all a measure of industrious versatility that none can now attain, standardized three branches of science in America; but a young man, little taught, yet studious and observant, who standing thoughtful on a mountain peak not in Darien but Tahiti, first learned a deep secret of the Pacific, and added to Darwin's theory of coral reefs the confirmation that even Darwin himself overlooked!

The Pacific still has many prizes for the observant explorer. Let the student who would discover some of them note the good example set by Darwin and Dana, and cross the great ocean early in his life, while he is yet young enough to have, after his return from its inspiration, many years for work; but if he finds it impossible to go early, better late than never!

SHAKESPEARE, THE OBSERVER OF NATURE

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OF Shakespeare's life, his personal habits, his ways of playing and working; with whom he was intimate and of his journeyings, we know little or nothing. But a host of editors, commentators, and essayists have examined all the minutiæ of his environment, the plots, characters, and language of his works; much of it repeatedly. One is reminded by this diligence of the methods employed by the prefect's agents in Poe's tale of "The Purloined Letter." "Shakesperiana," as a result of all this research, far outstrips, in quantity at least, the literature which has thus far in the world's history ever accumulated about any other man and his work. Poor Will, should he awake to-day, and should he undertake the heroic task of editing all these writings, what a blue pencilling of pretty volumes there would be!

Yet this tangle of speculation and criticism, though full of weak and knotted strands, is in the main a literature we prize. While, therefore, it is difficult to find a Shakesperian theme that has not been interestingly and exhaustively discussed it does seem that the great writer's nature observations are worthy of a fuller treatment than has hitherto been accorded them. In the following paragraphs some attempt is made to show the range of subjects these cover, and their surprising accuracy in view of the crude state of scientific knowledge in Shakespeare's time.

Manners and customs change, and with them human points of view. By the inventions of three hundred years our social environment has been greatly altered. Yet the rich legacy bequeathed us by that grandest age of English literature, the sixteenth century, has enabled us to image Elizabeth's court and country with a degree of accuracy that is impossible with other remote periods in the history of modern civilization. But as some of the details in the picture, some of the essentials even, lack confirmation, our inferences may often be in error. Man varies his standards of conduct from year to year, but nature is a more staid dame—although she too changes her garb with the seasons, the cut and the cloth of the dress she assumes in each remains the same through the centuries. Thus the climate of Great Britain, the contour of her hills and vales are now as they were in Shakespeare's time. The same trees grow in the forests, among their branches flutter the same birds, on the forest-floor bloom the identical wild flowers that the poet's eye loved to dwell upon. If then we study the poet's nature lines and draw con-

clusions from them, we may be sure at least that the outdoor world has much the same aspect as it had in his day.

Editors in general express their amazement at Shakespeare's wonderful and accurate knowledge in natural science. Yet it is doubtful whether they collectively appreciate how wonderful this really was. They compare Shakespeare's observations with those of modern scientists and note that these agree. They judge Shakespeare's natural history in the same manner that they would that of a modern novelist and find it more than simply trustworthy. What this means can only be made apparent by an inquiry into the degree of progress in natural science that had been made up to his time.

Extremely curious fallacies were entertained and accepted by Shakespeare's scientific contemporaries, to say naught of the popular beliefs. Comparison of Shakespeare's observations with those which obtained in the published natural histories of his day enables us to realize how far he was in advance of the authors of such books. One such volume is Bartholomew's "De Proprietatibus Rerum," of which Mr. H. W. Seager, an English writer, says:

> There can be no doubt that Friar Bartholomew's book was the standard authority on natural history in Shakespeare's time.

From Batman's translation of Bartholomew is quoted the following description of bees and their habits:

> Many have assayed and found that often bees are gendered and come of carrions of cattle. . . . And bees choose to their king him that is most worthy and noble in kindness and firmness, and most clear in mildness, for that is chief virtue in a king. . . . And kindly the more huge bees are the more lighter they be for the greater bees be lighter than the less bees. . . . Also bees sit upon the hives and suck the superfluity that is in honeycombs. And it is said that if they did not do so thereof should spiders be gendered of that superfluity and the bees should die.

Next consider Shakespeare's version:

> For so work the honey bees,
> Creatures that by a rule in nature teach
> The act of order to a peopled kingdom.
> They have a king and officers of sorts;
> Where some, like magistrates correct at home,
> Others, like merchants, venture trade abroad,
> Others, like soldiers, armed in their stings,
> Make boot upon the summer's velvet buds;
> Which pillage they with merry march bring home
> To the tent-royal of their emperor;
> Who, busied in his majesty, surveys
> The singing masons building roofs of gold
> The civil citizens kneading up the honey,
> The poor mechanic porters crowding in

Their heavy burdens at his narrow gate,
The sad-ey'd justice, with his surly hum,
Delivering o'er to executors pale
The lazy yawning drone.

—"Henry V.," Act I., s. 2, l. 187 et seq.

While this poetical account may not be wholly in accord with the observations of a Fabre, yet the whole description is sane, it is in no sense outré. If Shakespeare gives us so faithful an account in verse, where he is entitled to a poet's license in dealing with the facts, how accurate an interpreter he must have been; since he had to rely necessarily on his own observations for all such descriptions; contemporary natural science abounding in the grotesque vagaries cited above.

The country about Stratford-on-Avon was Shakespeare's haunt until his twenty-first year. Warwickshire, in which Stratford-on-Avon is located, is in the English Midlands. Of these the Avon district is notable for its soft, reposeful beauty. Every aspect has the appearance of being well rounded off, of being well fed. The land is a series of lowlying plains, separated by rolling hills, its surface suggesting that of a summer sea undulating in gentle swells. Through the lowest vale creeps the Avon water, whose slow advance along shore is all but stopped by the soft friction of the earth margin. In such quiet reaches extensive tracts of bulrushes grow luxuriantly. A fringe of yellow water-lillies generally marks the outer edge of this growth while on the shore side the green meadow grass bends down to meet the water. Where the banks are a bit higher the rich alluvial soil sustains a wealth of beautiful wild flowers. Shakespeare himself has described the stream for us:

The current that with gentle murmur glides,
Thou know'st, being stopped, impatiently doth rage;
But when his fair course is not hindered,
He makes sweet music with th' enamell'd stones,
Giving a gentle kiss to every sedge
He overtaketh in his pilgrimage.
And by so many winding nooks he strays
With willing sport to the wild ocean.

—"T. G. of V.," Act II., s. 7, l. 25 et seq.

To any one who has looked through the clear waters of some slow-flowing stream to its pebbled bottom, at a point where it tinkles with swifter motion over some slight descent, the application of the adjective "enamelled" must be fascinating. With a single word, Shakespeare images a page of description.

From the shores of Avon the land rises on both sides in gentle sweeps to the uplands, of which both the slopes and summits are dotted with stately clumps of oak and ash, the remnants of a once great forest. In Shakespeare's time, contemporary authors tell us, quite extensive tracts yet remained standing. The uplands from which the timber has

been cut are just high enough to be breezy, and from their ridges one commands quite a view of the surrounding country.

Amid such pleasant scenes Shakespeare's boyhood and youth was spent. Undoubtedly he had all a boy's love of sport, and with his school companions enjoyed many an outing in the woods and fields. On these outings he applied to natural phenomena the same intelligent observation, linked with imagination, that he was to apply so effectively in later life to men and events. As a boy and youth Shakespeare gained his nature lore, and acquired also the scientist's painstaking method of investigation. It must not be inferred from this that Shakespeare parted from nature for all time, when, at twenty-one, he rode away to London. But many of his observations are so essentially boyish, they exhibit so plainly the boy's point of view, that we can not mistake the time when these brain impressions were made. Experiences creep ever and anon into his writings that are curiously part of the career of a healthy-minded youngster rambling on half holidays through Warwickshire woodlands, and beside the Avon water. He tells us:

> **Men like butterflies**
> **Show not their mealy wings but to the summer.**
> **—"Troilus and Cressida," A. III., s. 3, l. 78–9.**

We all know of this *mealiness,* but we feel that it was never the observation of a grown man. Only the boy, whose thumb and forefinger have closed on the struggling captive, can duly appreciate the poet's conception. It is a boy too, who invites you:

> **I prythee, let me bring thee where crabs grow;**
> **And I with my long nails will dig thee pignuts;**
> **Show thee a jay's nest and instruct thee how**
> **To snare the nimble marmozet; I'll bring thee**
> **To clust'ring filberts and sometimes I'll get thee**
> **Young scamels from the rock. Wilt thou go with me?**
> **—"Tempest," A. II., s. 2, l. 171 et seq.**

No one could resist such an invitation. Again it is possible that the deer-stealer of later fame is foreshadowed in the youthful poacher who knew

> **The trout that must be caught with tickling.**
> **—"Twelfth Night," Act II., s. 5, l. 25–6.**

Other passages charmingly present the boy. We can not do better than suppose ourselves permitted to accompany the poet and a party of his schoolboy friends, out for an all-day ramble. According to agreement, we meet early.

> **The lark at break of day arising**
> **From sullen earth, sings hymns at heaven's gate.**
> **—Sonnet XXIX.**

and

> **The busy day**
> **Wak'd by the lark, hath rous'd the ribald crows.**
> —"T. and C.," A. IV., s. 2, l. 8 et seq.

for these the

> **Merry larks are ploughmen's clocks.**
> —"L. L. L.," A. V., s. 2, l. 912.

and to their music we wend our way through

> **The quaint mazes in the wanton green**

past the

> **Nine-men's morris.**
> —"M. N. D.," A. II., s. 1, l. 99, 98.

to the edge of the village common. We avoid the highway, choosing, instead, to follow one of those byways for which England is famous; byways that respect no man's vested right, but cross the midst of fields and turn not aside at the hedge of a private park, for they assert emphatically, as one writer has put it:

> **That although the land is yours when you buy it, the outlook from every point belongs to the people, and can not be bought!**

In the dewy grass beside the path we chance upon a snail and find by experiment that he, his

> **Tender horns being hit,**
> **Shrinks backwards in his shelly cave with pain,**
> **And there all smother'd up, in shade doth sit,**
> **Long after fearing to come forth again.**
> —"Venus and Adonis," l. 1033 et seq.

Shakespeare's vivid memory of this incident enables him to introduce, without any incongruity, so homely a creature when his theme is love, moreover to use it in a comparison. In "Love's Labour Lost," Berowne declaims

> **Love's feeling is more soft and sensible**
> **Than are the tender horns of cockled snails.**
> —A. IV., s. 3, l. 337-8.

When at noon we find that

> **The sun shines hot.**
> —"H. VI.," Pt. 3, A. IV., s. 8, l. 60.

we turn into the woods where

> **The green leaves quiver with the cooling wind**
> **And make a chequer'd shadow on the ground.**
> **Under their sweet shade.**
> —"T. Andron.," A. II., s. 3, l. 14 et seq.

we loll, while Shakespeare weaves for us a thousand fancies. All too soon

> **The sun begins to gild the western sky.**
>
> —"T. G. of V.," A. V., s. 1, l. 1.

and we must turn on our homeward way. English twilights are long, and the yellow slanting beams from the low-hung orb of day twinkle and gleam among the path-bordering-trees for hours. In this golden light dance the gnats so fast, so furiously, disappearing so mysteriously, that Shakespeare propounds

> **And whither fly the gnats but to the sun?**
>
> —"H. VI.," Pt. 3, A. II., s. 6, l. 9.

a query no one of us can answer. In silence we trudge the last few miles while:

> **The crickets sing, and man's o'er labour'd sense**
> **Repairs itself by rest.**
>
> —"Cymbeline," A. II., s. 2, l. 11.

It were easy to multiply such pages from Shakespeare's life and the task is a delightful one. One can not fail to be impressed again and again by the acuteness and accuracy of his observations. When one essays to group these references under their different heads, one first realizes how extensive was his acquaintance with nature, animate and inanimate. The animal kingdom he brings oftenest to our attention. All the reptiles which were native to Warwickshire he knew; modern investigators have not been able to add to the number which Shakespeare notes in his poems and plays. In other phases of natural history he was equally well versed; to appreciate this we have only to examine his work systematically.

Alexander Pope declared of Shakespeare that:

> **Whatever object of nature . . . he speaks of or describes it is always with competent if not with extensive knowledge; his descriptions are still exact, all his metaphors appropriated and remarkably drawn from the true nature and inherent quality of each subject.**

This appreciation applies in its fullest force to Shakespeare's knowledge of birds. In this branch of nature lore he displays, indeed, the most exact and extensive learning. There are several reasons for this. The vale of Avon furnished exceptional incentives for the development of an ornithologist, because of the number of species that could be observed there. Other than the varieties of land-birds which regularly resorted to the meadows and woods of the Warwickshire country, seabirds, driven inland from the coast by heavy southwest gales, followed the course of the Avon as far as Stratford, and remained in that vicinity several days before again winging their way back to the shore. In spring and fall

migratory birds of many kinds halted there during their north and south flights.

Yet the variety of bird life found in Warwickshire only in part accounts for Shakespeare's great birdcraft. A very important factor in its acquisition was the great vogue of falconry in those days.

It is hard for us to conceive how widely popular this sport, now almost obsolete, was at that time. Mr. J. E. Harting, a British ornithologist, writes:

> In Shakespeare's time every one who could afford it kept a hawk, and the rank of the owner was indicated by the species of bird he carried. To a king belonged the gerfalcon; to a prince the falcon gentle, to an earl the peregrine, to a lady, the merlin; to a young squire, the hobby; while a yeoman carried a goshawk; a priest, a sparrowhawk; and knave or servant a kestrel.

A well-trained hawk was as much a source of pride to the falconer as a skillful hunting dog is to the modern sportsman. That Shakespeare was well versed in this pastime is evident from the numerous references to it which occur in his work, and from the number of its technical terms which he employs. Many of these direct allusions to falconry are interesting in themselves.

> **As confident as is the falcon's flight**
> **Against a bird!**
>
> —"Rich. II.," A. I., s. 3, l. 61.

he exclaims, and in "King Henry VI." we have the old sportsman's chronic failing, his fondness for patronizing comments—expressed by Cardinal Beaufort:

> **Believe me, cousin Gloucester,**
> **Had not your man put up the fowl so suddenly,**
> **We had had more sport.**
>
> —"H. VI.," Pt. 2, A. II., s. 1, l. 45 et seq.

Similar passages are numerous in fact, the first part of this scene is altogether devoted to falconry talk, and abounds in the jargon of that craft.

As may be inferred, not all birds, to use the parlance of the day, were "flown at," moreover, certain birds were the prerogatives of the great. Among these may be mentioned the heron. This came about partly because such birds afforded better sport; also because the meaner species of hawk, that people of lower rank carried, could not cope to advantage with such large quarry. These restrictions only tended to make the devotee, whate'er his class, more observant of all the birds that came within his view. Such riveting of the attention must have keyed Shakespeare's powers of observation to the highest pitch. Where other falconers may have dismissed the unavailable bird with a glance, he no doubt beguiled his waiting for desired quarry by noting the habits

of those species that had nothing to fear from his hawk. Hunters to-day find game that is out of season most plentiful, and in all likelihood the rule held good in the sixteenth century. Yet it is wonderful how many kinds of birds Shakespeare knew.

He mentions all the species having popular names. We may well infer that he was acquainted with many more, for it must be remembered that Shakespeare was in some degree, no doubt, obliged to confine his allusions to species that were familiar to his audience. Yet he finds occasion to mention the eagle, buzzard, osprey, the different kinds of owls, the pelican, crow, raven and woodpecker, the magpie, jay, thrush, blackbird and bunting, the cuckoo, robin, sparrow and wren, the dove and the partridge. Besides these there are birds distinctively mentioned as flown at, the lapwing, the woodcock and snipe, also wild geese and duck. Of distinctly sea birds the guillemot and the cormorant are cited. The aptness and truth of the references he makes to these denizens of the air shows how conversant he was with their ways. What modern playwright or poet knows half this number of species well enough to use them in his diction?

The lark seems to have been a favorite with Shakespeare. It is mentioned again and again, and almost always associated with the morning.

> **Lo! here the gentle lark, weary of rest,**
> **From his moist cabinet mounts up on high**
> **And wakes the morning, from whose silver breast**
> **The sun ariseth in his majesty.**
>
> —"Venus and Adonis," l. 853 et seq.

The blackbird he describes as

> **. . . so black of hue**
> **With orange tawny bill.**
>
> —"M. N. D.," A. III., s. 1, l. 131–132.

The young of the lapwing "run almost as soon as they are hatched" we are informed by ornithologists, and Shakespeare has noted this peculiarity.

> **This lapwing runs away with the shell on his head.**
>
> —"Hamlet," A. V., s. 2, l. 193.

Perhaps the best way to show how intimately Shakespeare knew the facts will be to examine his so-called errors and especially one that has attracted some attention in the past, and apparently taxed the resources of commentators to explain. In several plays Shakespeare ascribes a certain habit to the cuckoo. These quotations are given below in their chronological order.

> **Why should the worm intrude the maiden bud?**
> **Or hateful cuckoos hatch in sparrows' nests?**
>
> —"Lucrece," l. 848–9.

And being fed by us you us'd us so
As that ungentle gull, the cuckoo's bird,
Useth the sparrow; did oppress our nest;
Grew by our feeding to so great a bulk. . . .
—"Henry IV.," Pt. 1, A. V., s. 1, l. 58 et seq.

But since the cuckoo builds not for himself.
—"Ant. and Cleo.," Act. II., s. 6, l. 28.

For you know, nuncle
The hedge-sparrow fed the cuckoo so long,
That it had it head bit off by it young.
—"Lear," Act I., s. 4, l. 237 et seq.

An investigation of these passages proved extremely diverting because of the varied ways in which the different critics and Shakespearian editors tried to explain, dodge or ignore the question—Was Shakespeare at fault in accrediting such habits to the cuckoo?

In the lines from "Lear," moreover, two disputed textual passages occur. The Globe edition has the last line:

That it had it head bit off by it young

which is awkward and meaningless. This line some other editions boldly change to just the opposite and have two "its," reading:

That it had its head bit off by its young.

Furness in the Variorum edition inclines to the reading

That it's had it head bit off by it young

explaining his "it's" as a contraction for it has, which would seem to give sense to the passage, *i. e.*, that it (the sparrow) has had it (the sparrow's) head bit off by it (the cuckoo) when still young.

Again in the case of the phrase "For you *know* nuncle" the Globe reading and the Variorum edition agree on the above; (nor is there anything said about a different reading in the Variorum). Yet Schmidt in his Shakespeare Lexicon defines "*trow* = believe" for this passage; and so it is printed in Knight's edition of Shakespeare's works. Now let us see what the commentators have to say regarding the natural history of the lines.

Mr. J. E. Harting, the ornithologist, after quoting all three passages, dodges the issue:

The solution of this question is the more puzzling from the fact that this parasitical habit is not common to all species of the genus cuckoo. An American species builds a nest for itself and hatches its own eggs. The habits of our English bird must always be as much a marvel to us as its remarkable voice, etc.

Mr. Chas. Knight, the Shakespearian editor, pins his faith to "trow,"

adopting this reading without question and triumphantly champions the poet as follows:

> There is a remarkable instance in his (Shakespeare's) discrimination between the popular belief and the scientific truth in his notice of the habits of the cuckoo. The Fool in "Lear" expresses the popular belief in a proverbial sentence:
>
> For you trow nuncle
> The hedge sparrow fed the cuckoo so long
> That its had its head bit off by it young.
>
> Worcester, in his address to "Henry IV.," expresses the scientific fact without the vulgar exaggeration, . . . a fact unnoticed until the time of Dr. Jenner by any writer but the naturalist William Shakespeare:
>
> And being fed by us you us'd us so
> As that ungentle gull, the cuckoo's bird,
> Useth the sparrow; did oppress our nest,
> Grew by our feeding to so great a bulk. . . .

Mr. J. E. Harting, some half dozen pages after his first dismissal of the subject, recurs to it again:

> The opinion that the cuckoo made no nest of its own but laid its eggs in that of another bird, which brought up the young cuckoo to the detriment of its own offspring, was well known to the ancients and is mentioned by Aristotle and Pliny.

The more recent scientific discussions of this bit of natural history are interesting reading, in view of the decided differences of opinion among the commentators. The Victoria History of Warwickshire, because of the thorough manner in which the various subjects are treated, is a valuable reference book on Shakespeare's native county. The section on the Ornithology of Warwickshire was written by Mr. R. T. Tomes, F.G.S. and corresponding mem. Z. S., who under the head of "the cuckoo" (although he makes no reference to Shakespeare) has the following sentence:

> I have long been of the opinion that the female cuckoo lays her eggs on the bare ground, from which she takes them in her beak and places them in the nests of other birds.

He cites instances when he has observed this transference of the egg.

Other British ornithologists, in general, believe that the cuckoo not only deposits its egg in some smaller bird's nest, but also that the cuckoo fledgeling, by an upward jerk of its rump, hurls the true offspring of its foster parents from the nest; and itself grows so large before leaving this that the foster parents are compelled to perch on the fledgeling's shoulders, in order to convey food to its gluttonous maw. Under the circumstances is it not a plausible enough theory, that Shakespeare did witness some such tragedy as is indicated in the Fool's lines;

and that he therefore needs no learned etymological or ornithological defense?

The other so-called natural history errors of Shakespeare are probably enough, as Mr. Knight contends, due to his reliance on books; as Knight puts it:

> Shakespeare derived his nature truths from observation, his untruths from books.

Such errors are:

> The toad, ugly and venomous,
> Wears yet a precious jewel in his head.
> —"As Y. L. It," A. II., s. 1, l. 13–4.

> Now I will believe . . .
> That . . . in Arabia
> There . . . is one phoenix.
> —"Tempest," A. III., s. 3, l. 22 et seq.

Knight, curiously enough, in view of his elucidation of the cuckoo episode, fails to note in this connection the rather obvious fact, that such errors are given as beliefs of the characters who express them, or, indeed, as expressions of their own skepticism, as in the case of the phoenix, and are, not therefore, to be construed as accepted by Shakespeare himself.

The limitations of this paper preclude considering in detail all the divisions of natural history that Shakespeare knew at first hand. It must suffice that we pick out several of the more noteworthy for examination. As in the case of the birds, Shakespeare's insects attract attention because of the remarkable number of species mentioned.

When we think of the very small number of insects that the average person, to-day, can call by name, how many less he knows, or remembers the habits of, and that even now only a very small proportion of the classified species have popular names; we can better appreciate the range and quality of that man's observations, who in the city, far from their haunts, wrote about, from memory, almost all the species possessing popular names, that were native to his youthful home. Mr. Robert Patterson, an entomologist (Treasurer of the Natural History Society of Belfast), found that the passages in Shakespeare containing notices of insects occupied "nine closely written pages of letter paper." He has not printed this list, but we may surmise from his language that he considered it extensive, in fact he says elsewhere that he was "surprised at the amount of natural history contained in the plays."

It needs only a short search to come upon a passage revealing more than a merely superficial knowledge of this topic. If a modern entomologist were made a dramatist, he could not better voice scientific fact than Shakespeare has in the lines:

There is differency between a grub and a butterfly; yet your butterfly was a grub.

—"Coriolanus," A. V., s. 4, l. 12–13.

It can not be too often reiterated that nature knowledge, such as displayed in this sentence, was nothing less than extraordinary in a sixteenth-century poet. Because the phases of the butterfly's life history are commonly known to-day, we are apt to pass over the expression without thinking of its real import—that at a time when natural history abounded in absurdities and superstitious beliefs, this man stated the facts. Again his uses of these facts and keen observations are at times imaginative to a fascinating degree. When Mamillius in "The Winter's Tale" whispers:

I will tell it softly;
Yond crickets shall not hear it.

—Act II., s. 1, l. 29–30.

his conception of the crickets as listeners, because they cease their clamorous chirpings, remaining absolutely silent as long as you converse in their vicinity, is a very pleasing fancy.

When the sun shines let foolish gnats make sport,
But creep in crannies when he hides his beams.

—"Com. of Errors," Act II., s. 2, l. 30–31.

And often, to our comfort, shall we find
The sharded beetle in a safer hold
Than is the full wing'd eagle.

—"Cymbeline," Act III., s. 3, l. 19 et seq.

are on the other hand passages embodying bits of philosophy which might well have found place in Bacon's essays.

There are, in other of these insect passages, unrivalled quaintness and suggestiveness. No other poet has surpassed in imagery the conceits Shakespeare has made familiar in the description of Queen Mab's chariot and its fittings.

Her chariot is an empty hazelnut
Made by the joiner squirrel or old grub,
Time out o'mind the fairies' coach-makers.
(Its) . . . wagon-spokes made of long spinner's legs
The cover, of the wings of grasshoppers
The traces, of the smallest spider's web.
Her whip, of cricket's bone; the lash of film;
Her waggoner, a small grey-coated gnat.

—"R. and J.," A. I., s. 4, l. 60, etc.

Here must be inserted too that queer stanza:

The fox, the ape and the humble-bee
Were still at odds, being but three,

Until the goose came out of door
And stay'd the odds by adding four.
—"L. L. L.," A. III., s. 1, l. 90 et seq.

This is sheer nonsense and would adorn Lewis Carroll's "Alice's Adventures in Wonderland."

Passing from animate to inanimate nature, we think first of flowers, the beautiful things of creation. Perdita's speech in "The Winter's Tale," so often quoted, claims first attention:

O Proserpina!
For the flowers now that frighted thou let'st fall
From Dis's waggon! daffodils,
That come before the swallow dares, and take
The winds of March with beauty; violets dim,
But sweeter than the lids of Juno's eyes
Or Cytherea's breath; pale primroses,
That die unmarried, ere they can behold
Bright Phœbus in his strength, a malady
Most incident to maids; bold oxlips and
The crown imperial; lilies of all kinds
The flower-de-luce being one.
—Act IV., s. 3, l. 116 et seq.

As has so often been pointed out, she keeps precisely to the order of the season, while Milton, in a like passage, flagrantly violates the calendar of nature.

Mr. Hamilton Wright Mabie has made the interesting discovery, that there is only one place near Stratford:

Whereon the wild thyme blows.
—"M. N. D.," A. II., s. 1, l. 249.

and that it is a bank along the path to Shottery. If we may judge by the context of this passage, the associations coupled in Shakespeare's mind with this path, and bank, were not nearly so unpleasant as some commentators would have us believe.

The subtleties of trees' growth and habits, their characteristics and individualities, have not been lost on Shakespeare. He notes the reflection where

There is a willow grows aslant a brook
That shows his hoar leaves in the glassy stream.
—"Hamlet," Act IV., s. 7, l. 167–8.

Only the under side of the willow's leaves are hoar; again Shakespeare's statement is perfectly exact. In the "Rape of Lucrece" we have

The cedar stoops not to the base shrub's foot
But low shrubs wither at the cedar's root.
—"Lucrece," l. 664–5.

which observation must always please the geographical botanist.

Shakespeare, while so widely conversant with the minutiae of nature, was not blind or indifferent to her broader aspects. For these, also, he had an appreciative eye. He noted the pageants of the clouds; the manifold shapes they assume:

> Sometimes we see a cloud that's dragonish;
> A vapour sometimes like a bear or lion,
> A tower'd citadel, a pendant rock
> A forked mountain, or blue promontory
> With trees upon't, that nod unto the world
> And mock our eyes with air.
> —"Ant. and Cleo.," Act IV., s. 12, l. 3 et seq.

The colorful picture he presents in the lines

> When daisies pied and violets blue
> And lady-smocks all silver-white
> And cuckoo buds of yellow hue
> Do paint the meadows with delight.
> —"L. L. L.," Act V., s. 2, l. 902 et seq.

is surely a laughing, happy one of spring; while again, what could be more realistic than the autumn he depicts in Sonnet 73:

> That time of year . . . behold
> When yellow leaves, or none, or few, do hang
> Upon those boughs which shake against the cold
> Bare ruin'd choirs, where late the sweet birds sang.

These very many nature notes, sprinkled almost uniformly throughout his work, show how intimately the nature lover was associated with the poet in Shakespeare's art. Their quality indicates the patient seeking for the inner reason of things, that is the characteristic of the man of science. Individually the passages please us as does a tinkling chime of silver bells. The striking applications that the dramatist makes of these lines show him, however, a master of his art. Critics assert that certain of these nature passages were independent compositions that were later fitted into the plays and poems where they occur (by their author) in order that they might not be lost. The story of the hunt, in Lucrece, is commonly mentioned as an example of such interpolation. Granted that this be true, has any one ever ventured to say that these passages serve no purpose, or that they are inapt? Quite the contrary! It is remarkable enough that, although critics disagree about almost all else, on this one point they stand united: Shakespeare's similes and metaphors are always appropriate and clear. The German Shakespeare scholar, Dr. C. C. Hense, has even found himself called upon to defend Shakespeare's unrestrained and literal use of nature truths with such correctness.

If fault can really be found with the poet's usage; Hense's defense of it is bold and convincing. He says:

Man hat wohl von Shakespeare gesagt, das er die Schönheit der Warheit und Wirklichkeit unterordne. In seiner Verwendung der Naturverhältnisse tritt eine Wahrheit hervor, für welche der delikatere Sinn der späteren Zeit die Emphänglichkeit zum Teil verlor. Die Dichter des Altertums, der Natur näher stehend, vergleichen mit unbefangener Naturfrische Menschen mit Tieren; der tadelnde Beigeschmack, welchen der Vergleich mit gewissen Tieren einschlieszt, war in dem unbefangenen Natursinn der Alten nicht vorherrschend.[1]

He then cites passages from Homer, Horace, and other classical authors illustrating the decidedly "unconventional" comparisons they commonly employed. Nor was this appropriateness of Shakespeare's nature references confined to the minutiae of his work. To quote another German author, H. Heine, every drama has

Sein besonderes Clima, seine bestimmte Jahreszeit, und seine lokalen Eigentümlichkeiten. Wie die Personen in jedem dieser Dramen, so hat auch der Boden und der Himmel, der darin sichtbar wird, eine besondere Physiognomie.[2]

Thus we have the action of Romeo and Juliet taking place in sunny Verona, while Hamlet and Macbeth live their tragic lives under the gloom and fog of northern skies.

Turn now from the poet's written interpretation of his feeling and observations to a contemplation of the man himself, as revealed by those lines. Shakespeare, the nature lover—this phrase in itself expresses one of the most delightful conceptions we have in the history of literature. The conception is all the more pleasing if we accept the conclusions drawn by Mr. C. Creighton in his curious book entitled "Shakespeare's Story of His Life," wherein he attempts to unravel the biography from allusions in the poet's work. According to it Shakespeare's life in large part must have been very unhappy, for it is a tale of naught but quarrels, disappointed ambition and heartburnings arising from misplaced friendships. In any case, although he did not avoid society as did Thoreau, Shakespeare's joy in a secluded footpath must have been great, particularly if he was so unhappy in his social life.

Imagine how his heart must have surged and expanded away from public haunt, finding

> Tongues in trees, books in the running brooks
> Sermons in stones, and good in everything.
> —"As Y. L. It," Act II., s. 1, l. 16–17.

[1] It is true that Shakespeare has been accused of subordinating beauty to truth and realism. This is only so because in his nature references a verity is apparent that a later generation has in part lost its ability to appreciate owing to the development of a greater fastidiousness. The classical poets, in closer touch with nature, compared man with the beasts in a very unconstrained and naïve fashion. Because of their unconventional attitude toward nature these early writers were not dominated by a number of modern taboos, including that of comparisons with certain animals.

[2] Its suited climate, appropriate season, and local peculiarities. As the characters in every one of these plays, so also the earth and sky depicted therein, have each their distinctive and characteristic aspects.

"Good in everything." What an amount of satisfaction may be expressed by the word good. We feel its real force, now, better, when we hear "goodly": "a goodly sight it was. . . ."

One thing which must always make us happy is that we may feel reasonably sure that the poet spent the last few years of his life at his boyhood home, and that he could in those years satisfy the longing so feelingly expressed in the lines:

> O God! methinks it were a happy life,
> To be no better than a homely swain;
> To sit upon a hill, as I do now,
> To carve out dials quaintly, point by point,
> . . . . . .
> Ah! what a life were this! how sweet! how lovely!
> Would bring white hairs unto a quiet grave.
>
> —"Henry VI.," Pt. 3, Act II., s. 5, l. 21 etc.

SHAKESPEARE AS HEALTH TEACHER

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ACCORDING to the notions of the age in which he lived, Shakespeare would hardly have been recognized as a "doctor of physic," but from the twentieth century point of view he was, and is, a great physician. A curer of disease he certainly was not, but as teacher of mental and bodily sanity he has had a clientele that is numberless.

So superior a mind must have had an aversion to the company of the average doctor of medicine of the time. Their "science," which he evidently sifted to the bottom, was largely nonsense, and their practise consisted chiefly in the indiscriminate letting of blood and the administration of sundry traditionary, and not always safe, concoctions. Had he joined their ranks, however, and become a "curer of the body," Shakespeare would have allowed little to escape his keen senses in his study of the sick, and his weighing of signs and symptoms would have been made with nice judgment. Above all, he would have "understood" his patient—he would have had a rare insight into the condition of mind underlying or resulting from the bodily derangement and felt the importance of ministering unto "the immortal" as well as unto the corporeal part of his nature. At least he would have been honest and would have admitted as much, if the sick man needed more "the divine than the physician."

Medical science in and about the year sixteen hundred was so limited and so steeped in astrology and metaphysics that its professional study could hardly have appealed to many, save those who delighted in one or the other of these vagaries. Indeed, metaphysics and astrology were necessary to fill up the great hiatus of ignorance of the body itself in health and disease. Neither of these speculative pursuits offered a very firm basis on which to establish the art of healing. Though much progress had been made in gross anatomy, the compound microscope had yet to be invented and the science of physiology was, as yet, practically a blank book. The processes of digestion were vaguely understood, but there was complete ignorance of respiration and of circulation, and the brain was only coming to be recognized as the seat of consciousness. There was as yet but a hazy guess at the nature of infectious disease.

Practitioners of physic still leaned heavily, for support of their otherwise usually supportless practises, upon the ancients. "Thus saith Galen" or "so rules Hippocrates" was prefixed to most medical for-

mulæ. The ascendancy of Galen was especially complete in England. True, the name of Avicenna was not unknown, and the learning of the Arabians was not wholly neglected. A lively leaven of independence of authority had also been set working in the middle of the sixteenth century by the audacious Paracelsus (mentioned by Shakespeare in "All's Well that Ends Well") who dared to proclaim that his shoe buckle knew as much as all the ancients, and, what was more modest and vastly more important, declared that he, as well as they, could study nature first hand. It is evident that some of the English men of medicine were equally free from the trammels of tradition, for William Harvey was but fourteen years younger than Shakespeare. But, among all but a few, Galen was the medical god; the normal condition or "temperament" of the body was believed to depend upon the right mixture of the four elusive elements of the Greek thinkers—hot, cold, moist and dry—while from faulty proportioning of these there arose "distempers," and from distempers, under certain external conditions of food, of air, or more subtle phenomena, there developed disease.

Ailments—their cause and cure—were then, as now, matters of common conversation. Each man diagnosed his neighbor's complaint and suggested his own favorite remedy. There were even popular health books—and not bad ones. The "Castell of Helth," probably the first of these, was compiled (chiefly from Galen) in 1554 by no less a person than Thos. Elyot, Knight, privy councillor to Wolsey, intimate of Cromwell, etc. Its publication aroused the ire of the profession because of the sacrilege of the translation into the vernacular, because the translator was a layman, and for less worthy reasons. Fifty years later, when Shakespeare's earlier plays were leaving the press, Thomas Cogan, a humble physician and teacher, published the "Haven of Health, made for the comfort of Students." Shakespeare may have glanced through this work, which displayed some little wit and good sense, but for the material of which the author acknowledged himself much indebted to Master Elyot, "his Castell of Helth."

Then, as now, however, it was not so much the invention of cures for its ailments that was most needed for humanity, but an insight into the cause, and, therefore, into the prevention of disease. In London and in the village of Stratford (were rural conditions worse than urban then, as they usually are now?) men lived in the most filthy fashion, and they unwittingly reaped the consequences of their uncleanliness. Even John Shakespeare, father of the dramatist, well-to-do chief magistrate though he became, was fined for having a dunghill in his front yard. The condition of the rest of his premises is not pleasant to contemplate, and yet it is said that his illustrious son, in his first year, escaped the plague which carried off one sixth of the population of Stratford, only because his home was the most comfortable and sanitary in

the place. To the older scourges of unsanitary Europe, there had been recently added by the voyagers to new worlds some new plagues. Notable among these acquisitions was syphilis, which wrought havoc among all classes, and which, despite its own tendency to self-destruction and the brilliant work of modern medicine, still reaps a plenteous and hideous harvest of death and deterioration.

Whether Shakespeare's home surroundings saved him as an infant from his first experience with the plague, it allowed him opportunity for the fullest unfolding of his bodily powers, and gave him the appreciation of the feeling of health. He lived in a village of less than fifteen hundred inhabitants; there was a river in which to fish and swim, and there were inviting fields over which to rove and hunt with horse and hawk and hound. He could draw a "good long bow" and was well practiced in self-defense with quarterstaff and sword. That he made use of his opportunities for physical education is evidenced by the lines of autobiography scattered through his plays.

His stay in the public school was brief, and his health was unaffected by study. Cogan found that students then "be commonly valetudinary, that is sickly." Shakespeare did not belong to this class. His was a "lusty" youth, which led, by suitable living (despite some probable excesses and escapades), to a lusty age, for it is not believable that one who looked with so rare and philosophic vision at the strutters upon life's stage, could himself have been guilty of much of their weakness. Besides, the very great man is seldom given to dissipation. There is too much else for him in life.

In Shakespeare's earlier plays there is (saving the introduction of Pinch the "hungry, lean-faced villain" and quack into "The Comedy of Errors") little mention of physic and less of physicians, and he seems to have, in or out of his plays, no use for the services of a doctor of physic. He was approaching the age of sedentariness, however, had already learned that "unquiet meals make ill digestion," and perhaps other experiences of minor bodily ills followed and aroused his especial interest in such matters. At any rate, after 1597 the words "physic" and "physical," used often in the general sense of something salutary, appear frequently.

In "Henry the Fourth" (1597–1598) Shakespeare exhibits considerable knowledge of medical matters, Falstaff furnishing the material of his public clinic. He pictures accurately the bodily changes of senility; he mentions apoplexy, the gout, the pox (syphilis), and epilepsy; and in speaking of grief as leading to apoplexy he makes Falstaff say, "I have read the cause of its effects in Galen." The remark of Prince Henry

> . . . . . If he be sick
> With joy, he will recover without physic,

shows his observation of the effects of mental states on bodily, and vice versa.

Shakespeare's interest in "physic" and his intimacy with physicians may have been simultaneous; perhaps the latter preceded the former. His opinion of the average doctor of the day is presented in probably a not much exaggerated way in his Doctor Caius, in "The Merry Wives of Windsor" about the year 1600. This and the plays of the next four years are full of fun and sarcasm at the expense of the profession, with little hint that there might be in it any but charlatans and ignoramuses.

> **Will you cast away your child on a fool and a physician?**
>
> **He hath abandoned his physicians, madam; under whose practices he hath persecuted time with hope.**
>
> **Throw physic to the dogs. I'll none of it.**
>
> *Sir Toby.*
>
> **Sot, did'st see Dick Surgeon, sot?**
>
> *Clown.*
>
> **O, he's drunk, Sir Toby, an hour agone; his eyn were set at eight i' the morning.**

These were not expressions wholly respectful to the learned practitioners of medicine and surgery.

In "Troilus and Cressida" he again shows much familiarity with the bodily ailments of the age. By the time he wrote "Lear" and "Macbeth" (1605) he had evidently come upon more worthy material in the medical profession. The doctors of these plays are large-minded, sympathetic, and unhampered by tradition, above all exhibiting keen appreciation of the phenomena of mental aberration and a readiness to admit the fact that

> **. . . this disease is beyond my practice.**

It was not the habit of the majority of the doctors of physic to admit that they could not cure insanity, or anything else, by some material means. Shakespeare recommends for such patients rest, sleep, and a removal of "the means of all annoyance"; his decision concerning Lady Macbeth,

> **More needs she the divine than the physician,**

foreshadows, by three centuries, the general popular and professional agitation concerning the value of mental treatment of nervous disorders.

Shakespeare had full opportunity at hand for the study of insanity in many of its forms—the great majority of those afflicted were abroad in the land, though the more violent were chained in loathsome prisons or confined in little better "asylums." Far down into the seventeenth century the cause of insanity was laid at the door of demonology and witchcraft, and it is to be remembered that hospitals for the insane and

their humane treatment date back little more than a half century. Like a true scientist, Shakespeare shows chief interest in the border-line cases; and, to this day, the critics, after close examination of his most famous study, "Hamlet," have been unable to say whether the subject was or was not insane. The dramatist would probably have said that he was both. Shakespeare must have had a deep fellow feeling for the insane, especially for those so near to mental health. There must have been, beneath his careful delineations, more than mere art for art's sake, and there was painstaking truthfulness not in exhibiting some spectacular cures but in lauding the effects of the commonplace influences of

> Our foster-nurse of nature

and of

> Sleep that knits up the ravelled sleeve of care.

Not only did he warn against the conditions which push men across that narrow and invisible line which forms the boundary between sanity and insanity of the mind, but, as Mr. Rolfe said, Shakespeare "went out of his way" as a playwright to preach, even to the warning against the danger from a common cold, the gospel of bodily health.

In *Coriolanus* (1606) he gives a considerable number of lines to the subject of the interdependence and need of harmony among the organs of the body. The other structures rebelled against the stomach and

> . . . . . accused it:
> That only like a gulf it did remain
> I' the midst o' the body, idle and unactive,
> Still cupboarding the viand, never bearing
> Like labor with the rest.
> . . . . . .
> "True it is," quoth the belly,
> "That I receive the general food at first,
> Which you do live upon; and fit it is,
> Because I am the storehouse and the shop
> Of the whole body: but if you do remember,
> I send it through the rivers of your blood,
> Even to the court, the heart—to the seat o' the brain;
> And, through the cranks and offices of man,
> The strongest nerves and small inferior veins
> From me receive that natural competency
> Whereby they live."

We are strongly reminded of Shakespeare's greatest contemporary, Cervantes, who makes his hero say to Sancho "The health of the whole body is tempered in the laboratory of the stomach." Was Shakespeare familiar, at the time, with Don Quixote?

The dramatist more than once called attention to the result of taking too much food into the stomach, for

> Fat stomachs have lean pates, and dainty bits
> Make rich the ribs, but bankrupt quite the wits.

Falstaff is, in himself, an eloquent sermon on temperance.

Drunkenness received no gentle rebuke from Shakespeare's pen.

> What's a drunken man like, fool?

asks Olivia of Feste in "Twelfth Night" (1601).

> Like a drowned man, a fool and a madman. One draught above heat makes him a fool; the second mads him; and a third drowns him.

and in "Othello," Cassio bewails at length the folly of his intemperance.

> Oh God, that men should put an enemy in their mouths to steal away their brains! that we should, with joy, pleasance, revel and applause, transform ourselves into beasts! . . . To be now a sensible man, by and by a fool, and presently a beast! O strange! Every inordinate cup is unblest, and the ingredient is a devil.

Shakespeare paints the picture of the victim of venereal disease with no sparing of pigment and with no uncertain sweep of the brush. He even goes to the pains (not for the sake of creating a sensation) of exhibiting the foulness and baseness of the "sty" where

> Diseases have been sold dearer than physic.

It is in this same play, "Pericles"—nearly his last—that Shakespeare describes his ideal physician, or some real doctor of physic whom he admires. Possibly he had in mind his son-in-law John Hall; but Shakespeare himself was most worthy of the lines:

> . . . . . 'Tis known, I ever
> Have studied physic. Through which secret art,
> By turning o'er authorities, I have
> (Together with my practice) made familiar
> To me and to my aid, the blessed infusions
> That dwell in vegetatives, in metals, stones;
> And I can speak of the disturbances
> That Nature works, and of her cures; which doth give me
> A more content in course of true delight
> Than to be thirsty after tottering honour,
> Or tie my treasure up in silken bags
> To please the fool and death.

Shakespeare was not a student of sanitation, for the sources of infection, other than in a most hazy way, were as yet unknown. Had he lived to-day he might have pointed a telling finger at our public and private uncleanliness. It is probable that he was the victim of filthy

conditions at Stratford, for he died of a fever of not long duration. Doubtless he was, in this illness, ministered to by his son-in-law who had gained an enviable reputation as a physician and was much sought after by "those of more than ordinary understanding" and even by "such as hated him for his religion."

Though he died at fifty-two, Shakespeare had, according to the reckoning of Montaigne, a quarter century earlier reached, for that time, a good old age. Probably had it not been for some unavoidable cause, his superior physique, his appreciation of health, and his temperance would have preserved him many years more. He had, however, completed his work, for he had ceased to write, so far as we know, two years before his end.

He would not have considered himself a physician, but in the most important sense of being a teacher of health he stands among the first of that goodly company of non-professionals: Plato, Cervantes, Molière, Montaigne, Bacon, Locke, Addison, Wesley, Franklin, Carlyle, Beecher, Spencer, and others who, by both precept and practise, have been our greatest preachers of the gospel of health. As a minister to the mind, and, through it, to the fragile machinery through which it works, he has no peer.

AN ANALYTICAL STUDY OF ATHLETIC RECORDS

By GEORGE P. MEADE

CARDENAS, CUBA

IN June, 1915, Norman Taber, formerly of Brown University and Oxford, ran a mile in 4 minutes 2⅗ seconds, about two seconds faster than any amateur had ever been credited with running that distance. The question may have occurred to some of us at that time, "How far can the breaking of records continue?" Improvement in technique or in method may affect such records as the high jump and the pole vault; changes in apparatus may affect others such as the hammer-throw, but running is an act so natural and free from "knack" that it would seem probable that there is some rule governing the rate at which man can run—some limit which the records approach and beyond which they are not likely to go. Before looking into the matter further let us consider the class of figures with which we have to deal.

Athletic records have every right to consideration as scientific data. Races are timed by at least three skilled timers; distances are accurately surveyed and are remeasured in case a claim for a record is to be made; strict rules are observed to prevent mistake or fraud at the start and finish, and unusual circumstances, such as favoring winds, are noted by judges or referee. Finally the performance is investigated by a committee of the national athletic board of the country in which the race was run, and every circumstance which might affect the validity of the record is discussed before the record is sanctioned. (These precautions apply only to amateur athletics. Professional races are run under haphazard conditions, and timing is unreliable, so professional records will not be dealt with here at all.)

Athletic events may be divided into two classes—those which are run in all championship meets, and for which athletes practise regularly, and those which are run more rarely and for which practise is incidental. Of the first class, which we might term "standard" events, are the 100-yd., 220-yd. and 440-yd. dashes, the half-mile, mile, two-mile and five-mile runs. It is in these standard events that world-wide competition has been going on for many years. So many thousands of men have striven to break these records that they may be taken as closely approximating the best which *man* can do, rather than as representing the best which men have been able to do so far.

In order to compare the speeds at various distances it is necessary to compute the rate for some unit distance. For distances below five miles the seconds per 100 yds. is used as the unit. (For example, the record for the half mile is 1 min. 52½ secs., or 112.5 secs. The rate per 100 yds. is $\frac{112.5}{8.8}$ or 12.79 seconds.) For distances greater than five miles the rate is computed to seconds per mile.

Let us consider the world's best running records for the standard distances as given in Spalding's Athletic Almanac for 1915. The last column gives the rate per hundred yards, computed as shown above.

Distance	Time	Holder	Rate per 100 Yds.
100 yds.	9⅘ secs.	Kelly	9.60 secs.
220 yds.	21⅕ "	Wefers	9.59 "
440 yds.	47⅘ "	Long	10.86 "
880 yds.	1:52⅘ "	Meredith	12.79 "
One mile	4:12⅘ "	Taber	14.35 "
Two miles	9:09⅘ "	Shrubb	15.60 "
Three miles	14:17⅘ "	Shrubb	16.22 "
Four miles	19:23⅘ "	Shrubb	16.52 "
Five miles	24:33⅘ "	Shrubb	16.73 "

A study of these rates shows that for the 100-yd. dash and the 220-yd. dash the rate is practically identical. Here the fatigue in running the longer distance is offset by the greater effect of the delay at the start on the rate of the shorter dash. Beginning with the 220-yd. dash rate,

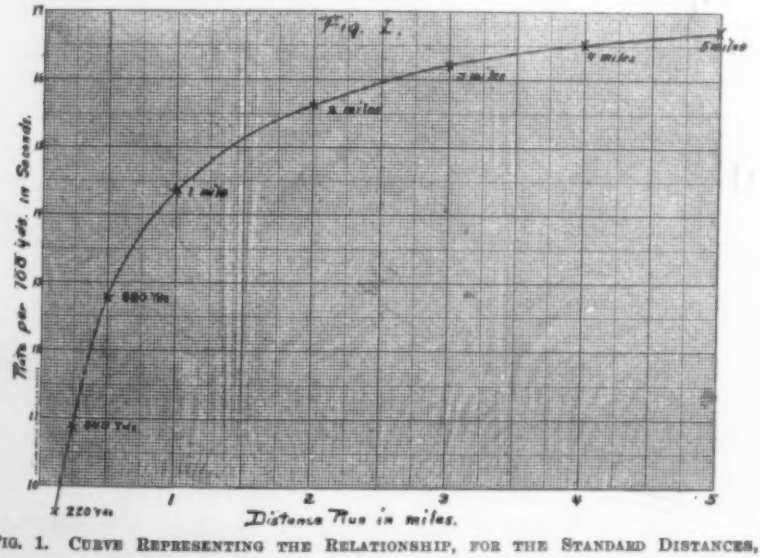

FIG. 1. CURVE REPRESENTING THE RELATIONSHIP, FOR THE STANDARD DISTANCES, BETWEEN THE RATE OF SPEED AND THE DISTANCE COVERED.

however, we note that the rates increase for each succeeding distance, but with a constantly decreasing increment.

Representing the rates as vertical distances and the miles as horizontal distances, we can show graphically the relationship between the rates, as in Fig. 1.

The smoothness of the curve connecting all the points plotted is striking—so striking, indeed, as to indicate strongly that there is an approach to a definite relationship between the various records which have been reduced by extended competition. No claim is made that the limit has been reached in the breaking of these records. Such a claim might be refuted by actual performance in the next athletic meet. But the probability of any marked change in the records represented by the curve is very remote.

To show the effect of competition on the rates, let us plot some of the second class of events (that is, those which are run more rarely). As instances we will choose the following:

Distance	Time	Holder	Rate per 100 Yds.
1,000 yards	2:12⅘	Sheppard	13.40
¾ mile	3:02⅖	Conneff	13.84
1½ miles	6:46⅗	Conneff	15.39

These points are plotted in Fig. 2, together with the curve already shown in Fig. 1. The points, as might have been expected, fall outside

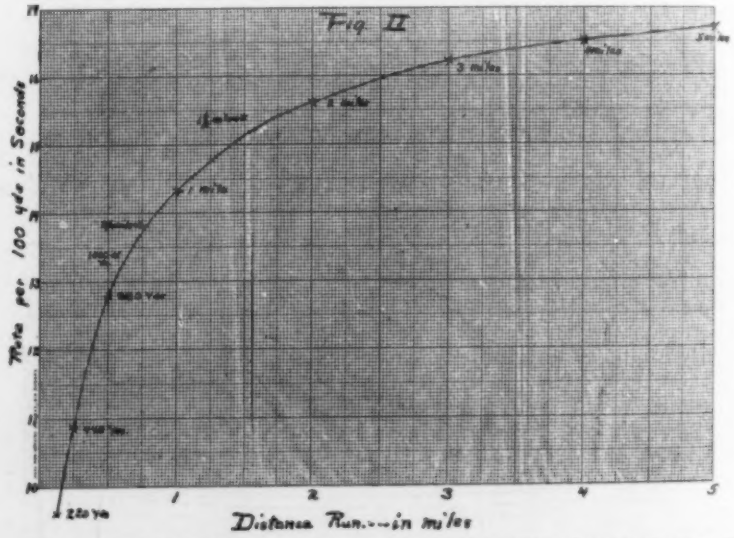

FIG. 2. THE SAME CURVE AS IN FIG. 1, TOGETHER WITH POINTS PLOTTED FOR RATE AND DISTANCE FOR 1,000 YDS., ¾ MILE AND 1½ MILES. Showing that for distances in which competition has been less keen the points fall outside the curve.

the curve. The rate for these less usual events is, therefore, greater than in the standard events. There is little doubt that if these distances were included in the regular schedule of championship events the records would fall until the points were included in our curve.

For convenience in studying the records for distances beyond five miles the rates are calculated to seconds per mile, instead of seconds per 100 yards. Following are the records and calculated rates:

Distance	Time	Holder	Rate per mile
440 yds.	47⅘ secs.	Long	191.2 secs.
¼ mile	1:52⅖ "	Meredith	225.0 "
One mile	4:12⅖ "	Taber	252.6 "
Two miles	9:09⅘ "	Shrubb	274.8 "
Three miles	14:17⅗ "	Shrubb	285.8 "
Four miles	19:23⅘ "	Shrubb	290.8 "
Five miles	24:33⅘ "	Shrubb	294.7 "
Ten miles	50:40⅘ "	Shrubb	304.0 "
11.82 miles	One Hour	Bouin	304.4 "
Fifteen miles	1:20:04⅘ "	Appleby	320.3 "
Twenty miles	1:51:54 "	Grossland	335.7 "
Twenty-five miles	2:29:29⅗ "	Green	358.7 "

These rates and distances are shown in Fig. 3. The one-hour record seems to be a continuation of the smooth curve obtained for the shorter

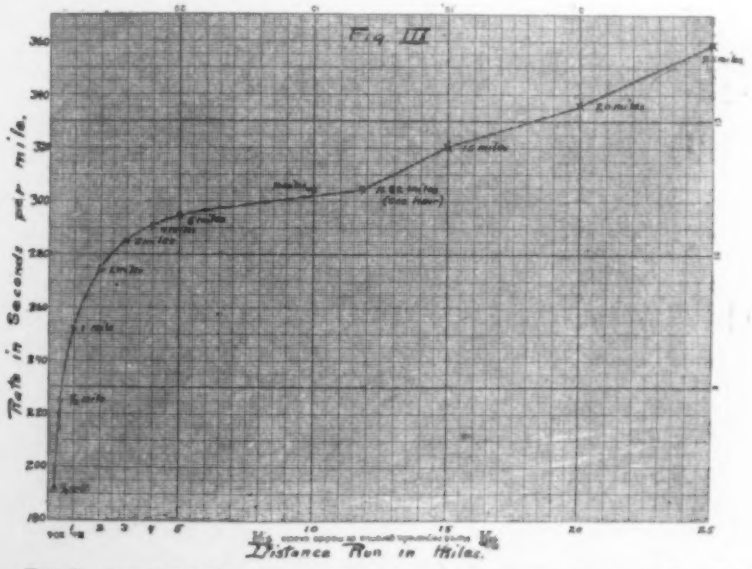

FIG. 3. THE RELATIONSHIP BETWEEN RATE OF SPEED AND DISTANCE RUN CONTINUED FOR RECORDS UP TO 25 MILES. (The rate here is in seconds per mile, instead of seconds per 100 yds., as in Figs. 1 and 2.)

distances, with the ten-mile record slightly out of line. It is of interest to note that this ten-mile record was made by Shrubb while he was

making the one-hour record formerly held by him. It is evident that if either Shrubb or Bouin had been running only ten miles, instead of for one hour on the day their records were made, the ten-mile record would be better and the point would fall within the curve.

Beyond the one-hour mark the curve breaks badly. Correct figures on professional races for the greater distances might tell a different story. In these longer races a money incentive might do more toward bringing out the full extent of man's abilities. Or it may be that whatever rule governs the records in the shorter distances does not apply in the longer ones. This does not seem as probable, however, as that the full possibilities have not been realized.

We have seen, then, that for those distances up to ten miles in which competition has been most intense there is apparently a rule governing the relationship between the distance covered and the rate. It may be that some mathematician who still has an interest in the sporting page will develop the formula on which this relationship is based.

THE ACCELERATION OF MORAL PROGRESS

By Dr. DURANT DRAKE
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WE Americans, and those among the warring nations of Europe who have leisure for reflection, stand aghast at the revelations of human hatred, cruelty, and barbarism which this past year of our Lord has thrust under our eyes. Where is all our boasted moral progress, our Christianity, our dream of the brotherhood of man? What was it all but a thin veneer over the black depths of brute selfishness and savagery? No wonder if many despair of the capacity of man to progress morally, and others look impatiently about for some new force to do for him what all the churches and societies have hitherto failed to do. It was, therefore, a timely as well as an interesting article which appeared in a recent number of *The Popular Science Monthly*[1] with the contention that the hope for moral progress lies along the line of eugenics.

Hitherto, the thesis of this paper ran, morality has been almost wholly a matter of social inheritance, a set of traditions imposed from without upon each succeeding generation, adopted by imitation and suggestion, perpetuated largely through fear of the penalties or social ostracism which follow upon deviation, but always more or less external to human nature itself, crossing its desires, demanding repression and conformity. Such a situation is pregnant with danger. Red-blooded youth will always be rebelling against its constraints; and any great wave of passion, like this present war, will fling its shackles to the four winds. Evidently there can be no secure morality until men are born with altered natures, with impulses and desires organically adjusted to the needs of their human situation, so that they instinctively and spontaneously choose the right. In short, our problem is that of "securing the preservation and perpetuation of a human stock that may be depended upon to lead moral lives without the necessity of much social compulsion." "Abiding human progress can come only through the improvement of the stock of the people."[2]

Now we may all agree that such an undertaking, if feasible, is desirable, and indeed of the utmost importance. Who does not long, at least in his saner moments, to be delivered from "the body of this death," from all the harassing temptations, the lusts and longings and passions, that lead him off on this tangent or that, deflecting him from

[1] By Professor F. Stuart Chapin, in the May, 1915, number.
[2] Article referred to, pp. 469–70.

the wise and virtuous life that might otherwise be his? If we could only have been born with an overpowering inclination towards virtue, how much trouble we might have been saved! And if by regulation of marriages, by sterilization or segregation of the immoral, or any other eugenic proposal, we can secure for future generations freedom from the tyranny of passion and a life of spontaneous virtue, we should be willing to make the necessary effort and sacrifice.

But is the undertaking in any degree feasible? Let us consider it more closely. Has any one any idea how to go to work to secure "a human stock that may be depended upon to live moral lives"? Whom shall we marry to whom? That we can breed a healthier race seems undeniable; and in so far as immorality is due to low vitality, pathological derangement, organic depression of spirits, we may hope for some relief. We may perhaps succeed in breeding a more intelligent race; and in so far as immorality is due to underwittedness and stupidity we may hope to diminish it. That this is the limit of expectation seems implied in the phraseology of the paper referred to; for the author sums up his contention by saying that "we ought to get into our *mores* the idea that the children of the present generation must be born of physically healthy and mentally capable parents."[3]

Certainly we should aim to breed a healthier and more intelligent race. But will that ensure us a more moral race? We do not need this present war to enforce this lesson. Think of the Alexanders and Attilas and Napoleons throughout history; think of the Macchiavellis, the Talleyrands, the Bismarcks. Are health and mental ability in any wise a guaranty of morality? On the contrary, unless they are early and successfully enlisted in the cause of right, they are the greatest source of danger to the community. The stupid and silly may oftener do wrong; but they are not clever or strong enough to invent wrongdoing on any great scale, or to escape detection in their petty crimes. It is the criminals of great vitality and mental alertness who baffle our detectives, or, still worse, get into positions of power where they can mislead the people and further their selfish ends without incurring liability to punishment. Thus the eugenic proposals, though admirable for other ends, are not adapted to the end here sought. The task of making a man healthy and intelligent can be, to some extent, performed before he is born, by the proper selection of parents. The task of making him moral must, perforce, wait till he is born and begins to grow up.

But why can not we breed directly for morality, by preventing the parenthood of the criminal and vicious? Some men seem to have a more fortunate moral endowment than others. One child has a congenital explosiveness of temper, one youth an imperious lustfulness. Another is naturally more sympathetic, gentler, or more fearless. We

[3] *Ibid.*, p. 471.

do not start side by side in our moral pilgrimage. Then why not prevent the birth of those who would be most seriously handicapped?

The reasons why this is impracticable are numerous and obvious. In the first place, it is questionable if any instincts are in themselves bad; man's potentialities of evil are also potentialities of good. An imaginative boy sees at the "movies" the tale of a successful crime; he imitates it, is sent to jail, and becomes a hardened criminal. But that same imagination, restlessness, inventiveness and daring, if properly utilized, might have made him a great inventor, or explorer, or aeronaut. A man shows cowardice in danger. But perhaps that is the result of an extreme sensitiveness to pain, a high-strung state of nerves, which would be a very valuable endowment for an artist or an actor. Your bad-tempered friend may be one who sees more clearly than you the faults of people and cares more passionately for his ideals; train him to patience and he may be worth ten of his apathetic neighbors. The apparently selfish man may be cherishing some purpose for the sake of which he is steeling his heart against the calls upon it; his determination, concentration of energy, single-mindedness, are rare virtues, and need only to be balanced by a clearer recognition of the rights of others. The lustful man is the man of passion, who under favorable circumstances might have become a great poet or patriot. Shall we dare to weed out of our human heritage any single instinct, and say that future generations will be better off without the potentialities which it offers?

But even if we could be sure which *traits* ought to be exterminated, we should still find it impossible to determine which *individuals* ought not to become parents. For to breed for any single trait would imply disregarding all the others that would inevitably be fostered or weakened by our interference. While we were carefully breeding out selfishness we might incidentally be breeding out energy, mental keenness, invention; or breeding in, say, an over-susceptibility to alcohol or to sex incitement. He that is abounding in sympathy may be lazy, shiftless, untruthful; he that is poor in that virtue may be rich in other potentialities. We are like the children in the "Birds' Christmas Carol"; he that had a necktie had no collar, and she that had shoes had no stockings. Who is competent to judge which of the concrete blendings of impulse is on the whole deserving of extinction? The problem would be as impossible of solution as that of the God who, according to the traditional conception, has to divide human beings into sheep and goats, the saved and the damned. The fact is that one person is worth saving in one respect, another in another.

The situation is further complicated by the fact that it is impossible to be sure which qualities of a man's character are inherited, and therefore transmissible to his children, and which are acquired. An irritable, ill-

tempered individual, for example, whom we might doom to sterility for that fault, might be merely suffering from some organic irritation whose removal would leave him as patient and sweet-tempered as another; even if it were never removed, his children would have no unusual natural irritability. On the other hand, traits which are deep-rooted, and will be passed on from generation to generation, may be lying dormant, for lack of the right influences to bring them out, and go unsuspected. We inherit, after all, only potentialities; and they are but dimly to be guessed through performance. The reproductive value of a man is to be measured not in terms of what he has done, but in terms of what he might have done under widely varying circumstances; it would only be by trying him out in every type of situation and under every sort of influence that we could know what is in him. All sorts of heroisms and lusts slumber in us, unknown even to ourselves; and to judge of the value of the potentialities which any given man is going to pass on to his descendants is quite beyond our powers.

Moreover, heredity is not so simple a matter as the enthusiastic eugenist is apt to assume. A child inherits the forgotten traits of a host of ancestors, and often fails to inherit the most striking of his father's or mother's traits. There are the facts of variation, and the complexities of the Mendelian law, to be borne in mind. When two people, each with a complex ancestry, marry, who can predict what the result in inherited instinct and capacity will be? A parent with a streak of insanity may bear a child who will be a genius; a parent who is a great philosopher or poet or statesman may have a son who is an idiot. We can hardly guess what strain, itself abnormal, may be of greatest value when blent with a different strain in parenthood. The mechanism of heredity is so intricate that with our present knowledge we are hardly competent to meddle with it, when it is a question of producing such a complex result as moral endowment.

Finally, the attempt to interfere with parenthood to the extent necessary to produce any appreciable changes in the instinctive endowment of future generations would not for a moment be tolerated in our times. Would you acquiesce in enforced sterility because you have, say, a congenitally explosive temper? or because you have shown a callous selfishness in pushing under your business rivals? When we think of state interference with marriages in the interests of morality, we imagine, of course, that we personally should be selected for parenthood, while the poor unfortunates in prisons and poorhouses would be prevented from marrying. But it may well be that many of the prisoners in Sing Sing have better blood in them than you. Are you sure that if they had had your opportunities they would not have done better with them than you? or that you, under their temptations, and with their lack of good influences and training, would not have landed in Sing Sing? It is

true that a large proportion of prisoners and paupers and prostitutes are feeble-minded; we may agree to their segregation for life or sterilization. But to a large extent crime and vice are the result, under fostering influences, of tendencies which exist in us all. And if we have had reasonably happy lives in spite of moral defects, we prefer to risk parenthood and trust to our children to get along as well or better.

What then? Is there no hope for the acceleration of moral progress? Yes, there is much hope. But it lies in the improvement of the old methods of moral teaching and training. Morality is something acquired by each generation, and not something transmitted by parents to offspring; we can greatly facilitate its acquisition. Morality is functional, not organic; it results from the way we use our powers and direct our instincts, not from their inherent nature. But we are not trying on any large and systematic scale to provide competent training in the art of life for our youth. We employ experts to teach them Latin and mathematics; we see to it that they know how to build bridges properly if they are to be engineers, or fill teeth properly if they are to be dentists. But we leave the most important training of all, the training that shall show them how to guide their desires and instincts, how to avoid the snares and pitfalls of life, how to be steadily and honorably happy, to the haphazard attention of parents, who are for the most part themselves ill-trained and ignorant of how to live. We need not despair of the efficacy of moral training, for we have hardly begun to try it.

The churches and Sunday-schools do a good deal, but theirs is little more than a one-day-a-week influence, on a minority of the population; and that more or less distracted or obstructed by theological interests, and offered in terms often unassimilable. Moreover, the homilies of the preacher are usually more or less discounted; it is his "job" to exhort. The actual perplexing problems of living are seldom taken up in the churches and discussed in a free and unbiased manner. It is clear that in our present chaotic religious situation, with numberless sects offering divergent doctrines, and the work of teaching done mostly by volunteers, young men and women of no special training or fitness for the work, we can not expect the crystallization and maintenance of clear and generally accepted codes through the work of the churches alone. The great task of moral education must be undertaken by the schools.

Our educational system is fairly good on its informative side, and in the mental drill it provides. But in its moral training it is inexcusably deficient. What if our school-superintendents and college presidents were to recognize that the prime function of education is to alter habits of conduct? What if our school system were to seek from the beginning to impart an interest in right living, were to discuss concrete problems of conduct, and to quicken conscience, by the many methods

known to skilful educators? It could then turn out multitudes of boys and girls trained to a code, as knights were trained in former days to courage and chastity and the service of the weak. What if loyalty to school and college were to come to mean primarily loyalty to that code; so that for a Harvard man anywhere to be detected in lying would be a shame to the college, or for a Yale man to use unfair methods in business would be to make his classmates blush and brand him as untrue to his *alma mater*?

Sinners there will continue to be, no doubt. Our human heritage includes instincts that are rebellious against any restraint; and the best of moral training may, now and then, result in failure. But the difficulties in the way of a task are no excuse for not undertaking it. We must give our youth insight into the possibilities of right living; we must arouse their interest in learning better ways, their enthusiasm for ideals. In this moral education, rather than in eugenics, lies our real hope for the raising of the general standards of moral conduct.

THE PUNCHBOWL: HONOLULU'S METROPOLITAN VOLCANO

By VAUGHAN MacCAUGHEY
THE COLLEGE OF HAWAII

HONOLULU, capital of Hawaii and strategic center of the north Pacific Ocean, is widely known as a tropical tourist resort, and as a great American naval station. The city has spasmodically expanded from an aboriginal cluster of grass huts to a cosmopolitan metropolis of sixty thousand people. It now stretches loosely along eight miles of the narrow coastal plain which lies between the mountains and the sea. The plain is of coral origin and rests upon the submarine flanks of the deeply carved volcanic mass that forms the bulk of the island. Scattered here and there over the plain are numerous craters that were thrown up by the final convulsions of the plutonic island-builders. These igneous disturbances ceased long ago and apparently are extinct. The silent craters remain as grim testimony of Oahu's prehistoric epoch of fire. Among the best preserved of these crater-hills is old "Punchbowl," a remarkable volcano lying in the very heart of Honolulu and commanding a magnificent view of the city and its lovely environs.

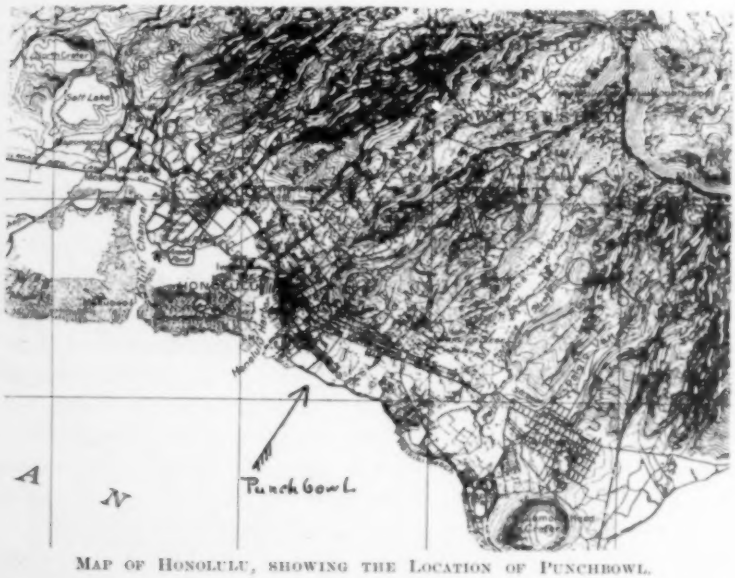
The Hawaiian name for this venerable crater is *Pu-o-waina* and it has a tragic significance. The original form, from which the modern spelling is abbreviated, was *Puu o waiho ana*, literally the hill of offering or sacrifice. The people of primitive Hawaii were dominated by the dreadful *tabu* system that once ruled all Polynesia. The penalty for any violation of its intricate regulations was death. *Pu-o-waina* was one of the places near Honolulu where the bodies of the offenders were ceremoniously burned. Near the highest point on the seaward rim is a flat, altar-like ledge. Below this ledge is a crack or orifice, once a volcanic vent. This gave a good draft of air and added to the suitability of the place for a sacrificial altar. Like place-names in all parts of the world, *Pu-o-waina* lingers for generations after the extinctions of the practises that once made it so effective.

In shape and structure Punchbowl is a fine example of a truncated volcanic hill produced by explosion. By truncated is meant, not that its top was ever blown off, but that it never possessed a sharply conical point or peak. From the time of its formation its top has been a bowl-shaped depression. The crater walls are composed of brown volcanic mud or tufa, which was violently ejected in a single titanic explosion.

PUNCHBOWL CRATER AND HONOLULU, AS VIEWED FROM THE MOUNTAINS ABOVE.

The huge column of superheated steam-charged mud and rock-stuff tore through the soft coral plain, shot to dizzy aerial heights, and dropped back around its vent. Thus was produced the symmetrical rim and bowl, and hence the name Punchbowl. There are numerous extinct volcanoes on Oahu and other Hawaiian islands that were formed in this same manner, and that with equal appropriateness might claim the fanciful title of Punchbowl.

The elevated coral plain up through which Punchbowl exploded is here about fifty feet above sea-level. The highest point of the crater is about five hundred feet (498) above the sea. The total diameter of the hill, including the basal slopes, is a full mile. The "bowl" has a rim-to-rim diameter of 2,200 feet from north to south, and 1,800 feet from east to west. The marked difference in the two diameters is shared with the other Hawaiian volcanoes of this type and is due to the wind



MAP OF HONOLULU, SHOWING THE LOCATION OF PUNCHBOWL.

conditions that existed at the time of the eruption. The usual winds of this part of the North Pacific in which the Hawaiian Archipelago is situated are the well-known trade-winds. These blow steadily from the northeast practically throughout the year. The trade-winds are so constant that the majority of the explosive cones are conspicuously one-sided. The strong wind deflected the eruptive column of volcanic mud. Consequently the bulk of the ejected material was dropped on the leeward, or southeast, side of the vent.

Punchbowl, however, is a striking exception to this prevalent elongation of crater axis in the direction of the trade-wind. It so happened

VIEW FROM PUNCHBOWL ON THE LOWLANDS. Diamond Head in the distance.

that just at the time of the Punchbowl explosion the dominant wind was not the trade, but the southeast, or "Kona," wind. This Kona wind blows erratically at infrequent intervals, mainly during the rainy season. The configuration of Punchbowl clearly shows that a strong Kona wind warped the erupted column to the northwest, and caused the deposits to fall chiefly on that side.

Several excellent automobile roads cut spirally around the furrowed sides of Punchbowl, through low gaps in the crumbling rim, and finally circle the basin floor. The basin has a depth of about one hundred and fifty feet. Its monotonous interior is covered with a sparse and stunted growth of such thorny plants as prickly-pear cactus, lantana, algarona, and *klu*. The lower part of the basin, that benefits most from the scant interior drainage, supports a thin grove of the algaroba, or *kiawe*, trees. Cattle and goats roam freely through the crater. On several occasions the bowl has been surveyed as a reservoir site, but other more favorable localities have been chosen. Since the military occupation of Oahu by federal troops, the commanding position of Punchbowl has recommended it as a location for batteries. In the days of the Hawaiian monarchy several small brass cannon were mounted on the brow of the hill, but these were removed many years ago. The basin is now being used as a rifle-range by the local militia. The slopes may some day mask the formidable artillery of Oahu's coast defense.

The outer slopes of Punchbowl are broadly scored by regular flutings or corrugations, the tooth-marks of long-continued erosion. These flutings and the numerous stone quarries make graphic sections and clearly reveal the structure of the walls. The tufa was deposited in well-defined layers of varying thickness, and permeated with coral lime. The layers strikingly show the double quaquaversal dip characteristic of volcanoes

of this class; their average angle is about twenty-five degrees. The quarries occur here and there along the lower skirts of the hill. The soft, easily-worked tufa has proved to be an excellent road material. Most of the streets and roadways in the vicinity are made wholly of tufa.

On the Punchbowl slopes one finds great quantities of a cinder-like volcanic ash. This is locally called "black sand." It occurs in extensive sheets over the Honolulu plain. The interior of Punchbowl crater is lined with this ash. A short distance eastward is a hill two hundred feet high, composed wholly of black sand. These evidences all point to a long series of stupendous black sand eruptions that devastated this region just as Vesuvius entombed Pompeii and Herculaneum. Some of the ash was ejected by Punchbowl, the remainder was discharged from other volcanoes in the neighborhood.

A very interesting glimpse into the geological history of Punchbowl has been afforded by an artesian well-boring near its flanks. The shaft first penetrated ten feet of black sand; then thirteen feet of *coral,* and finally about fifty feet of tufa. This succession shows that the crater was thrown up in relatively shallow water, coral reef grew over its flanks, and the reef in turn was covered by the volcanic ashes. The crater obviously was formed before the recent elevation of the Honolulu plain above the sea-level. According to Dr. Sereno E. Bishop the great symmetry and uniformity of Punchbowl's rim indicates that the crater was ejected in a *single rapid out-throw,* probably lasting a very few hours! He gives as the conjectural time of this explosion a period about 45,000 years ago.

Honolulu has steadily encroached upon the once-barren slopes of the volcano. In the early days Punchbowl was a remote outskirt, isolated

VIEW FROM PUNCHBOWL ALONG THE LOWLANDS AT THE FOOT OF THE MOUNTAINS.

A Steep Trail up the Tufa Slopes of Punchbowl. The summit is 200 ft. above the observer.

by dry plains from the tiny grass-thatched settlement on the beach. To-day its base underlies an important residence section in the center of the city. The Territorial Normal School is located on its seaward slope. The thrifty Portuguese, skilled in the gardening of Madeira's steep farmsteads, settled as easily and comfortably upon the arid walls of Punchbowl as did the amphibious Chinese upon the marshy rice-lands. The small, well-pruned gardens of "Portuguese Town" are crowded with luxuriant trees and shrubbery—figs, pomegranates, citrus and mango trees, grape-vines, avocadoes, papaias, bananas, and many other useful and ornamental plants.

A superb panorama of the surrounding country is visible from the rim of this city-girt hill. The distant purple Waianæ Range, the Wahiawa pineapple lands, glimpses of Pearl Harbor and the Kalihi channel, bowery Honolulu reposing beneath its rich canopy of tropical foliage, the valley floors bright with rice and taro, the long ridges rising into the cloud-capped mountains, the friendly palms of Waikiki beach, old Diamond Head bleached and gray against the brilliant blue of the seaward sky, the rusty red Kaimuki region, and, mountainward, the forested slopes of Tantalus: these compose a variegated picture of unique and lasting charm.

Equally rich and memorable is a tranquil moonlit evening on Punchbowl's rim. The gaunt, moon-bathed crater walls fade into the twinkling scattered lights of the city; the hushed air throbs with the roll of distant surf; the odorous trade-wind pours down from the shadowy mountains; tropic fragrances rise from the white-fenced gardens; these quiet beauties, subtly blended by the moonlight, bring a new appreciation of this ancient hill of fire and sacrifice.

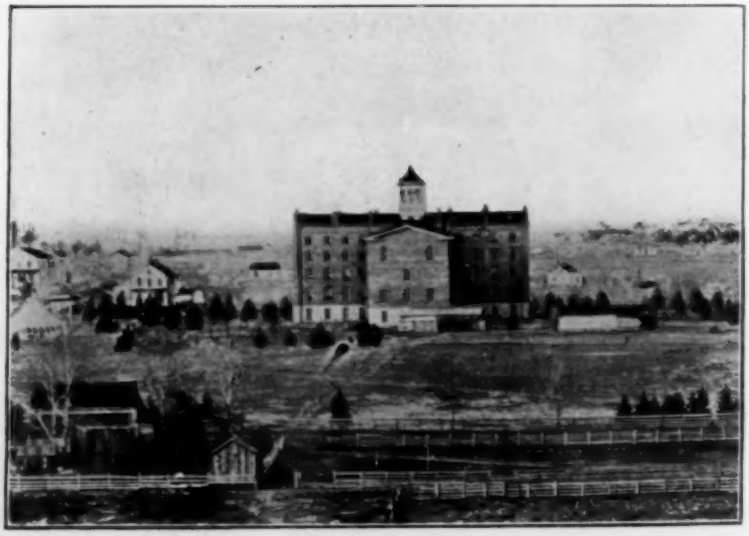
THE PROGRESS OF SCIENCE

THE AMERICAN CHEMICAL SOCIETY AND THE CHEMICAL LABORATORY OF THE UNIVERSITY OF ILLINOIS

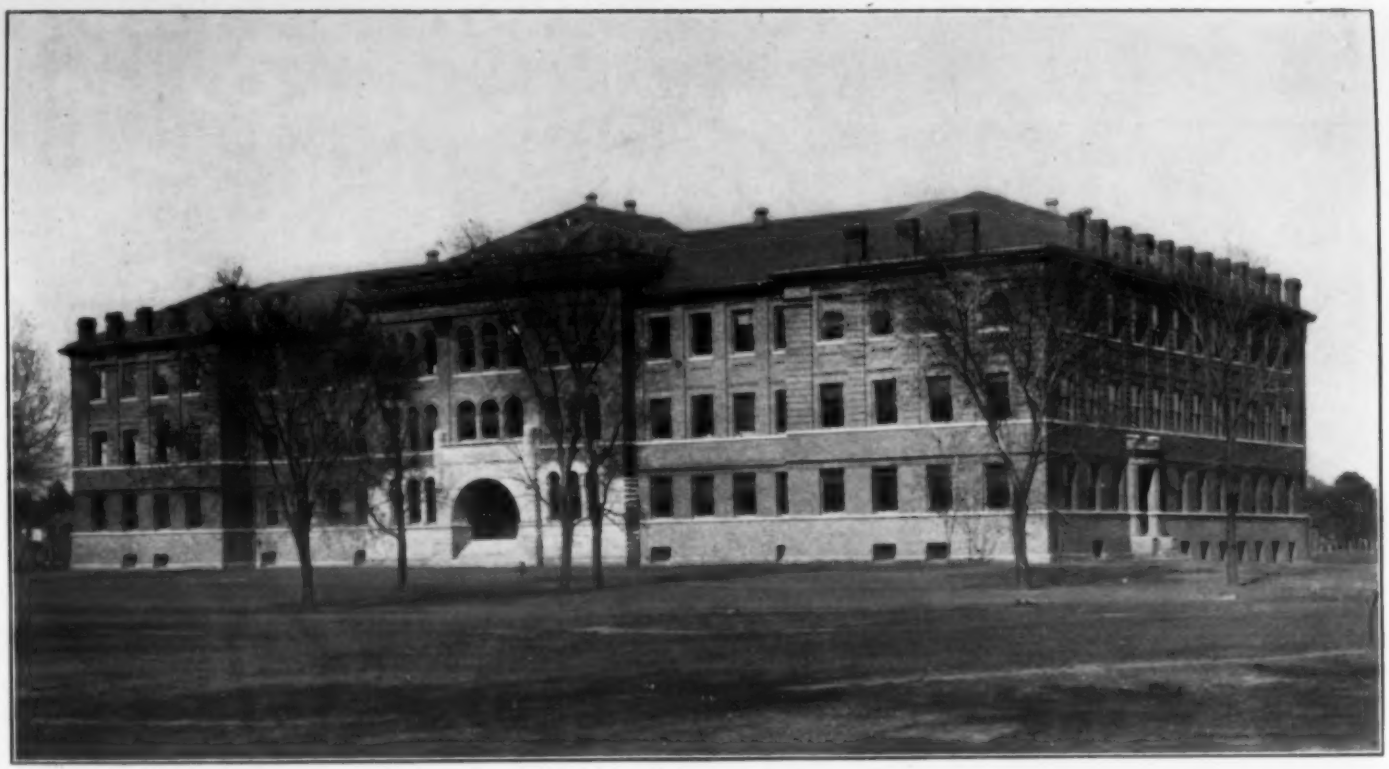
THE fifty-second meeting of the American Chemical Society was held at the University of Illinois, Urbana-Champaign, April 17–21, 1916. The meeting stands as the largest in the history of the society, the registration showing an attendance of 572 members and 157 guests, representing 32 states and 4 foreign countries. The two special features of the gathering were the dedication of the new chemical laboratory and an exhibit of American-made chemical products and apparatus. Excursions were made to the various departments of the university and to the chemical manufacturing plants at Danville. The entertainment included a review of the University Brigade of 2,100 men; a band concert by the First Regiment Band of 75 pieces; a smoker, and a banquet at which 402 covers were laid. Special entertainment for the ladies included receptions, concerts, luncheons and automobile drives.

At the council meeting the most important items of business were authorization of the publication of the ten-year index to *Chemical Abstracts*, and the appointment of a committee to consider the establishing of a publicity bureau whose duty it shall be to supply correct information of a chemical nature to newspapers and popular periodicals.

The first general session was held in the university auditorium, with Professor W. A. Noyes, chairman of the Illinois Section, presiding. President Edmund J. James, of the university, gave a cordial welcome to the visiting chemists. Professor Charles H. Herty, president of the society, responded in



THE FIRST BUILDING OF THE UNIVERSITY OF ILLINOIS. From a photograph taken about 1875. The Department of Chemistry was located in the basement of the rear wing, one window showing, just at the left of the shed. The only source of heat was a kitchen stove and water was supplied from a nearby pump.



The Chemistry Building, 1902.

HOME OF THE DEPARTMENT OF CHEMISTRY FROM 1878 TO 1902. This building, much changed in appearance, is the present Law Building.

an address in which was emphasized the need of trained chemists in the development of our national industries.

Sectional meetings were held in which a total of 283 papers were offered. These were distributed as follows:

Agriculture and Food	22
Biological	76
Fertilizer	1
Industrial and Engineering	26
Organic	53
Pharmaceutical	15
Physical and Inorganic	62
Water, Sewage and Sanitation	28

Two illustrated public lectures were delivered upon the subject of radium: Dr. Charles L. Parsons spoke on "The Production of Radium" and Dr. Curtis F. Burnam on "The Use of Radium in Treatment of Cancer."

The exhibit of chemical industries, arranged in the basement of the new building, proved to be one of the most interesting and valuable features of the gathering. Exhibitors to the number of 57 displayed a great variety of products of American manufacture, illustrating both the wide range of products of American ingenuity and the necessity for the development of certain other lines of chemical industry.

The dedicatory exercises were held in the university auditorium on Wednesday afternoon, with W. L. Abbott, president of the university board of trustees, presiding. In the opening address President James called attention to the fact that a university is no longer considered complete when it consists of a log with a teacher at one end and a student at the other; but a large factor in the success of a university in these days is the appearance of its campus and the equipment of its departments. The size and beauty of the new chemistry building at Illinois is an inspiring witness of the importance of chemistry.

"The Training of Chemists" was the subject of a very thoughtful and helpful address by Professor Alexander Smith, of Columbia University. All advancement in the science depends upon research and successful research requires thorough training. The entire chemical course should have all its instruction as well as the arrangement and equipment of the laboratories point toward greater efficiency of the chemists.

Dr. W. R. Whitney, member of the United States Naval Board, in a stirring address on "Research as a National Duty," told his hearers that he was tired of seeing the United States play the part of a trailer among na-

THE CHEMISTRY BUILDING, 1916. View from the tower of University Hall, looking southeast. In the foreground is the old portion of the building; the fire wall separating the new part is shown on both the north and the south portions of the roof.

tions; that leadership must come through systematic and thoughtful scientific research. Progress has been slow because we are just beginning to appreciate the value of research. Many of our institutions of learning are better known for their footwork than for their headwork. Colleges and universities must take the lead in research, for there is no better type of preparedness than research which is effective and persistent.

Upon the opening of the new laboratory, the department of chemistry occupies its fourth home since its organization in 1868. The first quarters were in the basement of the rear wing of the first university building, where heat was supplied from a kitchen stove and water was obtained from a near-by well. In 1878 the department was provided with a separate laboratory, a three-story brick building which is used now as the home of the College of Law. A much larger building was erected in 1902 and this building which is shaped like the letter "E" forms a part of the present completed structure. The present building forms a hollow square, 230 feet by 116 feet, the main lecture-room and the machinery for ventilation being in the court. The working space comprises 3.77 acres. Each laboratory is distinctive in that its arrangement and equipment are planned for its own peculiar type of work. Abundant provision is made for research in various lines of work. The present valuation of the entire plant, including equipment and supplies is about $540,000.

THE HYPOTHESIS OF AVOGADRO

THE molecular hypothesis of Avogadro was proposed in 1811. Eight years before, John Dalton had put forward the atomic hypothesis, which bears his name, to account for the laws of definite and multiple proportions and the law of combining numbers. According to this hypothesis, an atom is the smallest particle of an element

which can enter into or be expelled from chemical combination. If the attempt is made, however, to determine the "smallest combining weight" of an atom, the theory shows itself to be defective in that it lacks a standard for fixing the atomic weights of the different elements. In 1808 J. F. Gay-Lussac had observed that when two gases react chemically, the volumes which react bear a simple ratio to one another and to the volume of the gaseous product of the reaction. It follows at once if elements in a gaseous state unite in simple proportions by volume, and if the elements also unite in simple proportions by atoms, then the number of atoms in equal volumes of the reacting gases (at the same temperature and pressure) must be simply related. But even so, we still have no means of determining the numerical value of this relation, and therefore can not use the discovery of Gay-Lussac as such to determine relative atomic weights.

Avogadro (1811) went one step further in suggesting that this volume relation pointed out by Gay Lussac is the simplest possible, viz., *equal volumes of all gases, at the same temperature and pressure, contain the same number of ultimate parts, i. e., molecules.* A distinction is made between the elementary atoms and the small particles of a gas. Assuming that the small particles of a gas are aggregates of a definite number of atoms, Avogadro called these aggregates molecules, to distinguish them from the ultimate atoms. Avogadro thus modified the atomic hypothesis and adapted it particularly to gases. The hypothesis of Avogadro has been confirmed by such an abundance of subsequent work that it is now placed among the well-established laws of chemistry and physics. The same hypothesis was announced independently by the French physicist Ampère in 1814. By Avogadro's hypothesis equal volumes of gases contain the same number of molecules, consequently, the relative density of a gas is proportional to its molecular weight. The determination of the relative molecular weight of a gas is thus reduced to a laboratory measurement—the determination of the relative density of the gas.

After the proposal of Avogadro's hypothesis efforts were made to work out a reliable system of atomic weights; but chemists persisted in using and abusing the terms, "atomic weight," "combining weight" and "molecular weight" in every conceivable way, with the result that rank confusion prevailed in chemical literature. The confusion was increased by the attempt of Avogadro to apply the hypothesis to substances which could not be vaporized. This state of affairs led ultimately (1840) to the abandonment of the hypothesis by most chemists. Only Avogadro and Gaudin accepted it but without furnishing further evidence.

In the forties, however, a new epoch was begun in the history of Avogadro's theory, when Gerhardt recognized its value for the determination of formulas. Among the first to adopt the views of Gerhardt was Laurent, and these two men worked together earnestly for a period of about ten years, with the result that more and more attention was given to their views. At the death of these men in the early fifties, the work devolved upon the younger chemists—Cannizzaro and Kekulé. It was Cannizzaro who finally (1860) cleared up the confusion by showing just how the molecular hypothesis could be used to solve the problem of the relative weights of the atoms. Cannizzaro pointed out very distinctly the difference between atoms and molecules—"equal volumes of gases, whether they be simple or complex, contain an equal number of molecules, but not an equal number of atoms"—and proved that the molecular hypothesis was in harmony with all known facts. In addition, Cannizzaro called attention to the fact that Avogadro was the first to suggest this hypothesis. At the Congress of Chem-

ists at Carlsruhe in 1860, due largely to the initiative of Kekulé, Cannizzaro played a leading rôle. Lothar Meyer said (1860) after reading Cannizzaro's pamphlet, "the scales fell from my eyes, my doubts disappeared, and a feeling of tranquil security took their place." And while the hypothesis of Avogadro still remained a subject of controversy for some years, the day was won.

THE AVOGADRO MEDAL AND THE WORK OF PROFESSOR MORSE

In 1911 an international congress of scientists met in Turin, where Avogadro was formerly a professor in the university, for the purpose of celebrating the hundredth anniversary of the famous "Hypothesis" and of honoring the memory of its author. Out of the funds contributed for the occasion 1,500 Lire were set aside for an "Avogadro Medal" to be awarded, during the year 1915 or soon thereafter, by the Academy of Sciences of Turin, to the one who in its judgment should have published during the three-year period, 1912–1913–1914, the most notable contribution (experimental or theoretical) in the domain of molecular physics. It was this medal which was awarded at a meeting of all the sections of the Accademia Delle Scienze Di Torino on February 6, 1916, to Professor H. N. Morse, of the Johns Hopkins University, for his work upon "The Osmotic Pressure of Aqueous Solutions." This investigation was begun, after considerable tentative study of the problems to be solved, about 1899, and it has since been carried out under the auspices of the Carnegie Institution of Washington. A report on the progress of the first fourteen years of the work is given in Publication 198 of the Institution.

It is impossible to give in the space available any adequate outline of the investigation of Professor Morse and his co-workers, Drs. Frazer and Holland; but a few brief statements may be useful by way of orientation. In 1877, W. Pfeffer, then professor of botany at Basel, published under the title "Osmotische Untersuchungen" an account of his endeavors to measure osmotic pressure by means of porous cells lined with a "semi-permeable" membrane consisting of potassium ferrocyanide. The phenomena described by Pfeffer were impressive, and his quantitative results were accepted as at least approximately correct. He attempted the measurement of very moderate pressures only, and the concentration of his solutions was given in percentages. No one seems to have concerned himself about the *molecular* concentration of Pfeffer's solutions until 1887 when Van't Hoff published his epoch-making conclusions regarding the analogy between gas pressure and the osmotic pressure of solutions. Van't Hoff's conclusion that the latter would be found to obey the laws of Boyle and Gay-Lussac for gases was based, in part, on the recalculated results of Pfeffer's experiments. To chemists the way now seemed clear to a satisfactory experimental study of the molecular condition of substances in solution; *for it was only necessary to measure their osmotic pressure, and, apparently, Pfeffer had shown how this could be done.* Probably in nearly every working laboratory in the world attempts were soon made to repeat the experiments of Pfeffer as a preliminary to the investigation of solutions through their osmotic pressure; but every such attempt failed.

All serious attempts to measure osmotic pressure directly were soon abandoned, except by Professor Morse and his co-workers. The reason why all previous investigators (himself included) had failed to attain even to the partial success of Pfeffer, and why Pfeffer himself had not obtained better results, is shown in his chapter on "Membranes." A fundamental condition of success in the direct measurement of osmotic pressure is found to be that the semi-permeable membrane shall

consist exclusively of "plugs driven with great force into the mouths of the pores of the cell wall where they open upon the surface of the space occupied by the solution." But how were these "plugs" to be driven into place with such force that no pressure can displace them? The solution of this problem was the electrolytic method of depositing semi-permeable membranes which was devised by Professor Morse, and which is now the only method in use for the building up of osmotic membranes.

It was necessary, however, in order that deposition occur in exactly the right positions, namely, just within the inner mouths of the pores, to secure a texture of porous cell wall of a hitherto unknown degree of fineness. The requisite degree of uniformity and fineness of texture of porous cell wall was finally obtained, after four years of experimental work with clays from many sources. After developing to a high degree of precision all phases of the method, the formal measurement of osmotic pressure was begun. The most striking conclusions to be drawn from the results to date are: (1) that the magnitude of osmotic pressure in aqueous solutions depends on the *numerical ratio* of the solute to the solvent molecules; (2) that the laws of Boyle and Gay-Lussac for gases hold good for the osmotic pressure of solutions, but in a different sense from that supposed by Van't Hoff. According to Van't Hoff, and most others, a gram-molecular weight of a substance dissolved in water and diluted to a liter volume should, at zero degrees, exert an osmotic pressure of 22.26 atmospheres, the same pressure which an equal quantity of gas exerts at the same temperature when its volume is reduced to one liter. This is not true. It is true that if a gram-molecular weight of a substance is dissolved in 1,000 grams of water at zero degrees, and no hydration occurs to change the numerical ratio of solute to solvent molecules, the osmotic pressure of the solution will be found to be 22.26 atmospheres and at any higher temperature it will be what the law of Gay-Lussac would require.

SCIENTIFIC ITEMS

We record with regret the death of Dr. Lucien Ira Blake, formerly professor of physics and electrical engineering at the University of Kansas; of Dr. James William White, emeritus professor of surgery in the University of Pennsylvania, and a trustee of the university; of Dr. William Frederick King, chief astronomer of the Canadian government; of Professor F. Schenck, the director of the physiological institute at Marburg, and of M. Octave Lignier, professor of botany at the University of Caen.

Members of the National Academy of Sciences have been elected, as follows: Gregory Paul Baxter, professor of chemistry, Harvard University; Gilbert Ames Bliss, professor of mathematics, University of Chicago; Marston Taylor Bogert, professor of organic chemistry, Columbia University; Otto Folin, professor of biological chemistry, Harvard Medical School; Leland Ossian Howard, chief of the Bureau of Entomology, U. S. Department of Agriculture; Phoebus Aaron Theodore Levene, member in biological chemistry, Rockefeller Institute; Alfred Goldsborough Mayer, director of the department of marine biology, Carnegie Institution; Raymond Pearl, head of the department of biology, Maine Agricultural Experiment Station; Frank Schlesinger, director of the Allegheny Observatory, University of Pittsburgh.

The Royal Society has elected as foreign members: Prince Boris Galitzin, head of the Russian Meteorological Service; Dr. C. L. A. Laveran, of Paris, discoverer of the malarial parasite; Dr. Johan Hjort, director of Norwegian Fisheries; Professor Jules Bordet, the bacteriologist of the University of Brussels, and Professor H. Kamerlingh-Onnes, professor of physics at Leyden.

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